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ON THE MILLS-REINCKE PHENOMENON AND HAZEN'S THEOREM CONCERNING THE DECREASE IN MORTALITY FROM DISEASES OTHER THAN TYPHOID FEVER FOLLOWING THE PURIFICATION OF PUBLIC WATER-SUPPLIES.*

W. T. SEDGWICK, PH.D., SC.D.
Professor of Biology at the Massachusetts Institute of Technology, Boston,
AND
J. SCOTT MACNUTT, A.B., S.B.
Health Officer of Orange, New Jersey

TABLE OF CONTENTS.

		PAGE
I.	Introduction	490
II.	The Mills-Reincke Phenomenon	491
III.	Dr. Reincke's Observations on the Relation of Total Death-Rate to Water-Supply in Hamburg, Germany, 1894–97	492
IV.	Dr. Reincke's Studies on the Relation of Infant Mortality to Water-Supply in Hamburg and Altona, 1893–97	494
V.	Further Discussion of the Influence of Water-Supply upon Death-Rates in "Die Gesundheitsverhältnisse Hamburgs im neunzehnten Jahrhundert" (1901)	499
VI.	Mr. Mills's Further Studies on the Water-Supply and Total Death-Rate, etc., of Lawrence, Massachusetts, and His Address to the City Government of Lawrence, 1893–1902	505
VII.	Discussion by Mr. Allen Hazen, C.E., of the Water-Supply of Lawrence in Relation to the Total Death-Rate, 1901	506
VIII.	A Graphical Demonstration of the Lawrence Phenomena Published by Mr. Mills, 1904	507

* Received for publication April 27, 1910.

IX. Formulation of Hazen's Theorem, 1904 507
X. Other Data and Discussions Bearing on the General Subject . . 511
XI. A Recapitulation of the Literature, and a Brief Outline of the Work of the Authors 512
XII. A Graphical Demonstration and Discussion, by the Authors, of the Hamburg Phenomena 513
XIII. Graphical Demonstration and Discussion of the Lawrence Phenomena 521
XIV. Graphical Demonstration and Discussion of the Lowell Phenomena . 526
XV. A Graphical Demonstration of the Phenomena at Manchester, New Hampshire, a City Having a Water-Supply of Good Quality . . 530
XVI. A Comparative Study of the Data Derived from Lawrence, Lowell, and Manchester 535
XVII. Studies of Similar Phenomena in Some Other American Cities . 544
XVIII. Fluctuations of Population in Periods of Panic and Prosperity as Sources of Statistical Error 554
XIX. Summary and Conclusions 561

I. INTRODUCTION.

It is nowadays commonly understood that the purification of a polluted water-supply produces a marked decrease in the mortality from typhoid fever among persons using the water for drinking and other domestic purposes, but it is not as yet generally recognized that such purification produces also a marked decrease in deaths from other diseases.

In 1893–94 it was observed, independently, by Messrs. Hiram F. Mills, C.E., of Lawrence, Massachusetts, and Dr. J. J. Reincke, of Hamburg, Germany, that the purification of the polluted public water-supplies of Lawrence and of Hamburg, respectively, was producing a notable decline in the general death-rate of each of these cities. The attention of Mr. Allen Hazen was about the same time turned to the subject, and some years later, in a paper presented to the International Engineering Congress held at the St. Louis Exposition in 1904, he drew from an examination of the death-rates of certain cities which had radically improved polluted water-supplies the following conclusion:

> Where one death from typhoid fever has been avoided by the use of better water, a certain number of deaths, probably two or three, from other causes have been avoided.

This novel statement has not hitherto received the attention which it deserves, and in view of this fact, as well as in order to test

the range and accuracy of Mr. Hazen's conclusion, and also if possible to find an explanation for it, we have undertaken a careful examination of the vital statistics of a number of cities each of which has changed more or less suddenly from a polluted to a purified water-supply.

On August 14, 1908, we published in "Science" a preliminary communication announcing in part the results of our study and confirming Mr. Hazen's statement. We also contributed to the volume on "Tuberculosis in Massachusetts," prepared by the Massachusetts State Committee for the International Congress on Tuberculosis held in Washington, D.C., September 21 to October 12, 1908, and published in Boston in 1908, a paper entitled "On an Apparent Connection between Polluted Public Water-Supplies and the Mortality from Pulmonary Tuberculosis."

As will appear beyond, circumstances arose not long after the publication of our preliminary communication which made it seem desirable to repeat some portions of our work, and especially to take into consideration questions relating to the constancy of increase of population ordinarily estimated for American cities between census years. Some delay has thus been caused, but we now present the complete paper, which we venture to believe has meanwhile gained both in scope and in trustworthiness.

II THE MILLS-REINCKE PHENOMENON.

Shortly after the introduction of a filtered and purified water-supply into Lawrence, Massachusetts, in September, 1893, it was observed by Mr. Hiram F. Mills, C.E., a member of the State Board of Health of Massachusetts, then a resident of the city of Lawrence and chief engineer of the company controlling the water power of that city, that a marked decrease in the general death-rate of the city, and not merely in the death-rate from typhoid fever, was taking place. A few months earlier (May, 1893) filtration of the public water-supply had likewise been established for the city of Hamburg, Germany, and there also it was observed by Dr. J. J. Reincke, health officer of that city, that the general death-rate was declining more rapidly than could possibly be accounted for by the deaths from typhoid fever alone. To this important discovery, made thus inde-

pendently by Mr. Mills in Lawrence and Dr. Reincke in Hamburg, we have, because of its fundamental and far-reaching significance, applied the name of *The Mills-Reincke Phenomenon.*

Mr. Allen Hazen, the now well-known civil and sanitary engineer, who had long been more or less closely associated with Mr. Mills, visited Europe early in 1894, and while in Hamburg conferred with Dr. Reincke. He was impressed with the favorable results of filtration as observed and described by Dr. Reincke, and on his return to America he mentioned Dr. Reincke's observations to one of the writers (W. T. S.). He also stated in the first edition (1895) of his "Filtration of Public Water-Supplies" (p. 177):

> The death-rate [of Hamburg] since the introduction of filtered water has been lower than ever before in the history of the city, but as it is thought that other conditions may help to this result no conclusions are as yet drawn.

To this statement he appended in a later edition a table showing the deaths in Hamburg from typhoid fever and from all causes 1880–98, i.e., before and after the introduction of filtration.

III. DR. REINCKE'S OBSERVATIONS ON THE RELATION OF TOTAL DEATH-RATE TO WATER-SUPPLY IN HAMBURG, GERMANY, 1894–97.

The Hamburg filters began their work in May, 1893, and for that year the total death-rate showed an extraordinary decrease from that of preceding years, and a greater decrease than could be accounted for by the drop in the typhoid fever death-rate alone. Dr. Reincke's observations concerning this remarkable phenomenon were published from time to time in his Annual Reports[1] and may be quoted (in literal translation) or summarized as follows:

> In the year 1893 . . . . the total death-rate of Hamburg was 20.4 per thousand living. The mortality has never been so low before . . . . since the beginning of vital statistics in Hamburg in 1820. . . . . Manifestly the chief explanation of this favorable result is that the cholera of 1892 carried off an extraordinarily large number of people, especially of the weaker and less resistant, a part of whom would otherwise not have died until 1893. Whether the great improvement of the water has been of influence can be ascertained only after several years. The figures given in connection with infant mortality speak, however, strongly for this theory (Report for 1893, p. 15).

[1] *Berichte des Medizinal-Inspektorats über die medizinische Statistik des Hamburgischen Staates.*

For 1894 Dr. Reincke found the total death-rate to be 17.9 per thousand living.

Thus the mortality has receded still lower even than that of last year, which, as has been said, was the most favorable since the beginning of recorded vital statistics in Hamburg. . . . .

It is not altogether easy to offer a sufficient explanation of this favorable result. That the effect of the cholera of 1892 in carrying off prematurely many weak individuals is still operative, is not very probable, for the favorable conditions of 1894 appear in no age group so strikingly as among infants under one year, all of whom have been born since the epidemic. The death-rate of such infants is 201.9 per thousand [under one year of age] for 1894, as compared with a fifteen-year average of 287.1.

On the other hand, there is greater reason than in the preceding year for attributing a considerable share in the altered conditions to the improved water-supply, and the results for 1892 and 1893 of the influence of the water on the mortality of children from diarrhea and gastro-intestinal diseases are freshly confirmed (Report for 1894, pp. 11, 13).

In 1895 the total death-rate was 18.9 per thousand living, i.e., 1.0 more than in 1894.

Nevertheless the mortality was still more favorable by 2.7 per thousand than in 1890, the most favorable year before the introduction of filtration, and more favorable by 5.8 than the mean of the ten years before the cholera epidemic, i.e., 1882–91 (Report for 1895, p. 11).

For 1896 the total death-rate is reckoned at 17.1 per thousand living, the lowest ever observed in Hamburg up to that time.

Undoubtedly, the especially favorable result for this year is to be attributed chiefly to the cool wet weather from the middle of June to the middle of July, on account of which the high infant mortality of the summer was speedily cut down. . . . . That the year has passed as favorably as the three preceding years is fresh confirmation of the fact that *since the filtration of the drinking water the health conditions in Hamburg have improved in a quite extraordinary manner.* (Ist eine neue Bestätigung dafür, dass seit der Filtration des Trinkwassers sich die Gesundheitsverhältnisse Hamburgs in ganz ausserordentlicher Weise verbessert haben.) (Report for 1896, p. 11, italics ours.)

For 1897 the total death-rate of Hamburg "Stadt" (exclusive of the suburbs) is reckoned as 17.0 per thousand living. Again no rate so low had ever before been observed in the history of the city (Report for 1897, p. 12).

All the more weight must be given to the statistical statements made above because these were based upon an annual official enumeration of the population.

IV. DR. REINCKE'S STUDIES ON THE RELATION OF INFANT MORTALITY TO WATER-SUPPLY IN HAMBURG AND ALTONA, 1893–97.

In Dr. Reincke's Annual Report for 1892[1] we find a searching examination of the effect of water-supply upon infant mortality (particularly as due to gastro-intestinal diseases), which, because of its early date and its obvious importance for all students of the relations of polluted water to public health science, we shall either quote in careful translation or summarize, as follows:

It is usually assumed that the greater part of the deaths from gastro-intestinal diseases (*Brechdurchfall*)[2] in summer is to be explained by the high summer temperature, particularly through the action of warmth on the principal food of infants, i.e. milk. Our local observations, however, indicate that the matter is somewhat more complicated than this (p. 10).

Tables and diagrams are given of deaths from diarrhea and gastro-intestinal diseases, by months, for Hamburg and for Altona, with the mean monthly temperatures, 1871–92. In connection with these it is pointed out that the parallelism between deaths and high temperatures is not well marked, but that, on the contrary, there have been distinct outbreaks of these diseases during cold-weather periods. Also, that the curves for winter deaths of infants under one year from gastro-intestinal diseases are not parallel in Hamburg and Altona, as is the case with those of the summer period Reincke was unable to discover similar winter outbreaks in any other German city except, for certain years, in Berlin. We quote further and at length:

In Bockendahl's "Generalbericht über das öffentliche Gesundheitswesen der Provinz Schleswig-Holstein für das Jahr 1870," p. 10, we read: "Still more striking was an epidemic of gastro-intestinal diseases in Altona in January which proved fatal to 43 children. As the cases were observed in all parts of the city and the medical officer was unable to explain the phenomenon, he procured from the Gas and Water Company a statement regarding any interruptions in the supply of pure water to the city during the year 1870. He then learned that the city was supplied during a few days in January with unpurified Elbe River water. However little reason there may

[1] *Bericht des Medizinal-Inspektorats über die medizinische Statistik des Hamburgischen Staates für 1892*, published without date, but presumably late in 1893.

[2] We have not been able to find any exact English equivalent for the term *Brechdurchfall*, which denotes literally a condition characterized by diarrhea and vomiting. Mr. Hazen's rendition "cholera infantum," employed in his translations from Dr. Reincke in Appendix II of his "Filtration of Public Water-Supplies," does not appear to be allowable. *Brechdurchfall* is applied to both adults and children, but more frequently to the latter because gastro-intestinal disturbances are much more common during the early years of life. Throughout our translations of, and references to, the writings of Dr. Reincke and his associates, we shall render the term, with an approximation to accuracy, sometimes as "gastro-intestinal disorders," and sometimes, especially when it is applied to fatal cases, as "gastro-intestina diseases," without, however, necessarily implying by the latter phrase the existence of discoverable lesions.

be for regarding the connection between these two circumstances as proved, it is only proper that at all times interruptions in the pure water service be closely watched, because only in this way can reliable conclusions be reached and dangers be avoided. . . . . "

Dr. Kraus, who was at that time the medical officer of Altona, and who made the studies upon which Bockendahl's statement is based, subsequently became health officer of Hamburg; and, in a more lengthy opinion . . . . dated 1874, earnestly advocating the establishment of sand filtration in Hamburg, supported his position with the above observations, although with the caution that they are not to be regarded as entirely conclusive. In his annual report on the vital statistics of Hamburg for 1875 he suggests (p. 17) that the addition of unfiltered Elbe water to milk had probably been connected with the infant mortality of Hamburg, which mortality was very high in comparison with that of London (dass der Zusatz von unfiltrirtem Elbewasser zu der Milch wahrscheinlich an der im Vergleich zu London sehr hohen Sauglingssterblichkeit Hamburgs betheiligt sei.) He later repeated this opinion both in oral and in written statements.

Meantime so much material for observation has accumulated that his view may now fairly be regarded as proved. . . . .

Years ago, on observing the epidemic behavior of typhoid fever, in Altona . . . . I suggested that at the Altona waterworks disturbances in the action of the filters occurred in connection with frost, causing the distribution of water insufficiently purified. Wallichs of Altona, on the ground of further observations on typhoid fever, has come to the same conclusion, and lately Robert Koch, on the occasion of the small winter epidemic of Asiatic cholera in Altona, has proved that our hypothesis is correct. When open filters are cleaned in cold weather, it is a matter of common observation that the germs in the water are not sufficiently held back by the filters; and, as an actual fact, simultaneously with these disturbances of filtration there have occurred not only the explosive typhoid outbreaks of 1886, 1887, 1888, 1891, and 1892, and the Asiatic cholera outbreaks of 1871 and 1893, but also the increases of gastro-intestinal disorders in Altona. It can, therefore, no longer be doubted that these phenomena stand in the relation of cause and effect. It is thus explained also why in warm winters, as above mentioned, there have been no such outbreaks, and why gastro-intestinal disorders in winter have not been parallel in Hamburg and Altona.

In Hamburg the winter increases [of gastro-intestinal disorders] cannot be explained so simply. It seems probable, rather, that northeast storms, through the high tides which they cause, bring polluted water in greater quantity to the intake of the waterworks. It cannot be demonstrated that every such occurrence has caused an increase in infant mortality, but in many instances a noteworthy coincidence occurs. . . . . This point could be decided only by careful bacteriological determinations, and we have some such evidence for the last months of the year 1892, when daily bacteriological examinations of the city water were made at the Hygienic Institute, altho examinations of the river water itself were not begun until later. It was thus found that the bacterial content of the water varied between 200 and 600 at the end of October and the beginning of November; that it rose after November 19 to about 3,000; after December 4, to 4,000–5,000; and on December 18, to 7,500; and finally dropped rapidly in January to 200–500. On December 4 there occurred a storm-tide 2.6 m. in height, following a series of moderate high tides, and the December increase in infant mortality corresponded with the increase in bacteria in the water-supply mentioned above.

[TABLE 1.]

Stralau Waterworks, Bacteria per c.c.			Deaths from Acute Intestinal Diseases		
			Total	Gastro-intestinal Diseases	
				At All Ages	Infants under One Year of Age
1886					
March 23	145	March 21–27	...	4	4
March 30	**2,300**	March 28–April 3	34	20	18
April 6	500	April 4–10	**106**	49	46
April 13	125	April 11–17	99	46	44
April 20	360	April 18–24	56	25	25
April 27	105	April 25–May 1	46	22	22
1888					
March 1	16	March 11–17	24	4	4
March 15	**3,600**	March 18–24	**76**	29	29
		March 25–31	73	25	23
April 3	440	April 1–7	47	17	17
		April 8–14	47	21	21
April 16	125	April 15–21	50	20	18
		April 22–28	27	15	15
		April 29–May 5	28	12	12
1889					
January 16	112	January 13–19	28	4	4
		January 20–26	35	9	8
February 1	**1,730**	January 27–February 2	38	12	12
		February 3–9	65	17	17
February 15	1,600	February 10–16	**86**	22	22
		February 17–23	59	13	13
		February 24–March 2	35	8	8
March 4	2,400	March 3–9	47	13	12
		March 10–16	54	22	22
March 18	**4,800**	March 17–23	112	53	52
		March 24–30	**215**	118	116
April 1	264	March 31–April 6	120	61	60
		April 7–13	82	40	38
April 15	98	April 14–20	44	18	14
1891					
December 15, 1890	123	December 21–27, 1890	22	6	6
January 2, 1891	450	December 28, 1890–January 3, 1891	31	4	4
		January 4–10	25	3	3
January 15	1,325	January 11–17	25	6	6
		January 18–24	18	2	2
		January 25–31	36	7	7
February 1	**13,000**	February 1– 7	61	12	12
		February 8–14	**158**	61	61
February 16	4,000	February 15–21	**160**	50	50
		February 22–28	104	42	41
March 3	120	March 1– 7	88	29	29
		March 8–14	68	20	20
March 17	310	March 15–21	43	14	14
		March 22–28	38	10	10
April 1	85	March 29–April 4	28	9	9
		April 5–11	41	9	9
April 15	**800**	April 12–18	39	13	13
		April 19–25	**46**	16	16
May 1	140	April 26–May 2	25	11	11
		May 3– 9	49	19	18
1893					
?		February 5–11	23	4	9
?		February 12–18	56	20	19
?		February 19–25	**110**	41	41
?		February 26–March 4	**110**	40	39
?		March 5–11	69	20	19
?		March 12–18	39	10	9

A further support for this theory is found in the conditions at Berlin, where, likewise, frost has repeatedly interfered with filtration. The above table gives

the deaths from acute intestinal diseases, for several winter periods in which striking increases in mortalities in these diseases have appeared. It is obvious that, of the deaths enumerated in the first column, a predominant number is among little children. For comparison the bacteriological examinations are given, according to Plagge and Proskauer, of the tap water from the Stralau waterworks. Unfortunately the figures for 1892 are wanting.

No one can doubt, after this demonstration, that here also the delivery of insufficiently purified water every time cost the lives of many children. Still more striking is the evidence, from the publications of the Statistical Office at Berlin, that other parts of the city, supplied with better water from the Tegel works, completely escaped these increases in mortality, precisely as was the case in the well-known typhoid epidemic of February and March, 1889.

. . . . The fatal effects of the water are not confined, however, to those infants dying from well-defined intestinal diseases, for there is a large number besides who must have fallen victims with less striking intestinal symptoms. It appears, furthermore, that almost the only children affected were those not nursed by their mothers or by wet-nurses but fed on the milk of animals or other substitutes, which were mixt with more or less water.

So much for the winter conditions. As for the summer, the work of Plagge and Proskauer shows that the filters have then also occasionally delivered bad water. What influence this may have had is difficult to determine, since at that season gastro-intestinal disorders show ordinarily a high prevalence. But doubtless the influences of weather and water go hand in hand. This hypothesis is still more probable for Hamburg, because there, with the river water diminished during the summer months, the tides easily run up the river [carrying sewage to the intake] even without the aid of storms. This hypothesis is supported by the extraordinary prevalence of gastro-intestinal disorders in the unusually dry warm years of 1886, 1887, and 1892. If this be the case, when the intake is moved higher upstream and sand filtration is started, we may expect a substantial decrease of infant mortality. Not only should the winter increases entirely disappear, but those of the summer ought to be notably diminished. [How well this prophecy was borne out is shown by the table given on p. 121 of the "Gesundheitsverhältnisse Hamburgs im 19. Jahrhundert" published some years later, in 1901.] Moreover, it is not the infants only who will be benefited, for, as the Berlin figures show, there are also many cases of gastro-intestinal disorders among children from one to five years of age, and even adults do not entirely escape (pp. 13–17).

We may mention parenthetically that many of the valuable observations just quoted have been presented in English by Mr. Hazen in the first (1895) and subsequent editions of his "Filtration of Public Water-Supplies," Appendix 11.

Dr. Reincke's report[1] for the following year (1893) gives the mortality under one year of age, reckoned per thousand living in that age-group, for 1893 and earlier years, as follows (p. 17): 1885, 277.2; 1886, 368.8; 1887, 347.5; 1888, 289.8; 1889, 316.5; 1890, 276.3; 1891, 288.7; 1892, 404.8; 1893, **240.2.**

[1] For full title of reports see footnote, p. 492.

How uneven is the distribution by age months of this mortality of infants under one year of age, is shown by the following table.

Economy of space forbids our reproducing in full the table (p. 40) referred to, but we present a summary of it (Table 2).

TABLE 2.

AGES OF INFANTS DYING UNDER ONE YEAR, BY MONTHS.

	Average 1884–92 Inclusive Percentage	1893 Percentage		Average 1884–92 Inclusive Percentage	1893 Percentage
In the 1st month	24.2	27.0	In the 7th month	5.6	5.7
" " 2d "	12.9	14.3	" " 8th "	5.2	4.5
" " 3d "	11.0	11.9	" " 9th "	4.8	4.2
" " 4th "	9.1	9.6	" " 10th "	4.5	3.8
" " 5th "	7.8	7.2	" " 11th "	4.2	3.0
" " 6th "	6.5	5.9	" " 12th "	4.0	2.9
				100	100

Under "diarrhea and gastro-intestinal diseases" (Durchfall und Brechdurchfall), the following figures are given for the deaths of infants under one year of age for these causes by years:

1884	1,143	1889	1,557
1885	1,189	1890	1,198
1886	1,601	1891	1,500
1887	1,758	1892	2,541
1888	1,063	1893	857

Since I expressed myself in detail on these causes of infant mortality in my report for 1892 [already quoted above], it suffices for the present year [1893] to call attention to the highly significant decline in the number of these deaths and to the fact that this year the increase in mortality in December, often previously observed, is entirely absent. From the thorough studies recorded in last year's report it is highly probable that this favorable result is to be attributed largely to the filtration of the public water-supply, altho this point can be positively decided only after the experience of future years. Especially noteworthy is the considerable increase of deaths from these diseases in the second half of September, following a temporary pollution of the water which led at the same time to an outbreak of Asiatic cholera (pp. 43–44).

Three years later Dr. Reincke repeats a portion of the above table, adding to it the deaths from diarrhea and gastro-intestinal diseases for 1894, 1895, and 1896, which were 708, 918, and 767, respectively (see our Chart 1). He may well have remarked, in view of these figures together with the increasing population:

In no other diseases did the favorable influence of the better water-supply introduced in 1893 stand out so clearly as in these (Report for 1896, p. 46).

V. FURTHER DISCUSSION OF THE INFLUENCE OF WATER-SUPPLY UPON DEATH-RATES IN "DIE GESUNDHEITSVERHÄLTNISSE HAMBURGS IM NEUNZEHNTEN JAHRHUNDERT" (1901).

In 1901 there appeared a comprehensive treatise on the "Sanitary History of Hamburg in the Nineteenth Century," prepared under the editorship of Dr. Reincke.[1] In this work the declines in the total death-rate and in the death-rates from various diseases following the introduction of filtration into Hamburg are still further considered, and additional evidence is given for the existence of a relation between water-supply and gastro-intestinal diseases (particularly of infants). The observations on these points we have abstracted, mainly in literal translations and at some length, as follows:

1. General Death-Rate.

In the century curve of the general death-rate . . . . four peaks of specially high mortality stand out predominantly; these are the cholera years 1831 and 1832, 1848, and 1892 and the small-pox year 1871. Between them lies a greater number of lesser elevations, which are likewise to be attributed to greater or smaller epidemics of infectious diseases. . . . . Following each of these peaks there sets in regularly a compensatory decline in mortality.

Entirely different from these declines is that which set in after the cholera epidemic of 1892; for not only was this deeper than any other before it, but it has also lasted now throughout eight years—the beneficent result of the filtration of the water-supply which has been in operation since 1893 and to which we shall repeatedly return in connection with our consideration of the mortality from particular diseases (p. 90).

Comparing the twenty-five years 1872–1896 with the following four years, the average annual mortality has dropped from 25.0 to 17.2, a decrease of 7.8 per 1,000. In this improvement at least 6.1 per 1,000 may be regarded as due to general measures of sanitation, and of this again 3.0 at the very least as due to the betterment of the water by filtration. In this there have been reckoned for the infants under one year only 1.8 instead of 2.7, to avoid by any chance putting the figure too high; for cholera 0.8, and for typhoid fever 0.4 per 1,000. Even leaving the cholera out of account, an average improvement by at least 2.2 per 1,000 must be acknowledged. That gives, even with this thoroughly cautious and conservative calculation, for a population of, in round numbers, 340,000 (as the number stood in 1872), an annual number of deaths 748 fewer, and for the present population of 700,000, 1,540 deaths fewer in a

[1] *Die Gesundheitsverhältnisse Hamburgs im neunzehnten Jahrhundert*, den ärztlichen Theilnehmern der 73. Versammlung deutscher Naturforscher und Aerzte gewidmet von dem Medicinal-Collegium, Hamburg (Verlag von Leopold Voss), 1901. Translating freely, we shall apply to this work the English title given above—the term "history" being suggested by Dr. Reincke's preface. As the sections from which we quote bear no signatures, we assume that these sections are editorial and hence to be credited—at least in the main—to Dr. Reincke; many of the statements which we have quoted from his Annual Reports are, in fact, either paraphrased or amplified in the later work. In making this assumption we hope that we do no injustice to any of Dr. Reincke's collaborators.

year, which are to be accredited to the filtration of the drinking water. Undoubtedly, however, the real figures are much higher.

Through the improvement of the water-supply already discussed and the other contemporaneous measures of sanitation, Hamburg has caught up with most of the arger German cities, which hitherto had had more favorable sanitary conditions, and has surpassed many (pp. 310, 312).

2. Infant Mortality, Diarrhea, and Gastro-intestinal Diseases.

The term "Infant Mortality," as we shall use it here, has a special significance corresponding to the German "Saüglingssterblichkeit, d.i. der Sterblichkeit der im ersten Lebensjahre stehenden Personen," i.e., the mortality of infants under one year of age. As 90 per cent of all deaths from diarrhea and gastro-intestinal diseases (Durchfall und Brechdurchfall) in Hamburg in the nineteenth century occurred among infants under one year of age, we combine these heads as above.

It is certainly in consequence of sanitary improvements that, in spite of the growing factory-working population of the city, the *infant mortality has declined so extraordinarily since 1893*. And as a discussion, beyond, on gastro-intestinal diseases will show, *this abrupt and lasting improvement is to be attributed solely to the filtration of the drinking water* (Diese plötzliche und andauernde Verbesserung ist allein der Filtration des Trinkwassers zu danken) (p. 145, italics ours).

Under diarrhea and gastro-intestinal diseases it is noted that the mortality under this title is not statistically complete, since most of the deaths of infants from atrophy and debility (Atrophie und Lebensschwäche) really belong here. The evidence for this is found in their parallelism in seasonal and yearly prevalence.

Manifestly the as yet unidentified germs of these diseases are ingested by infants with their nourishment—never, however, in mother's milk, but only in artificial substitutes, especially cow's milk—which in some way or other has been contaminated with pathogenic germs. . . . . Among the dangerous contaminations of milk, a great part was played in Hamburg, until 1893, by the unpurified Elbe water, which was introduced into all the dwellings by the city water system. . . . . But since the water has been filtered, a gratifying decline in infant mortality has set in [see our Chart 3] (pp. 149, 150).

Since diarrhea and gastro-intestinal diseases attack chiefly infants under one year [who contributed 90 per cent of the deaths from these causes in Hamburg in the nineteenth century], and as no other diseases of infants claim nearly as many victims, it is evident why the century curve for these causes of death shows an extraordinary similarity to the curve of total infant mortality. Divergences occur only in exceptional years when for a time infants died in increased numbers from other diseases, or adults from diarrhea (p. 207).

The data given below concerning the connection of disease with drinking water suggest, moreover, the question whether the rise of the century curve since the '60's does not stand in a definite connection with the extension of the public water-supply of unfiltered Elbe water. The mean curve by months agrees, as would be expected, almost completely with the curve of deaths of infants from gastro-intestinal diseases. . . . . It virtually follows the atmospheric temperature, for continuous hot days usually unmistakably increase the number of cases of sickness. This subject, however, still needs for complete clarification much more thorough investigation than it has yet had. It must not be forgotten that hot days in May and June scarcely increase gastro-intestinal disorders. Furthermore, in midsummer the temperature is not the only decisive factor, for atmospheric humidity, the distribution of storms, and other factors which are of influence either upon the dissemination of pathogenic organisms or upon their multiplication in milk and other foods, also co-operate.

To *one* of the factors, which plays a part in the dissemination of the germs, attention has been drawn in Hamburg by the fact that the mean curve by months shows here a second rise, which, tho small, nevertheless reached in certain years (e.g., in January, 1883, 1890, 1892; in February, 1889; and in December, 1885, 1886, 1888, and 1891) a very considerable height. This rise occurred always in the winter, but cannot possibly be explained by colds, by life in small, badly ventilated rooms, by injury of milk consequent on heating, or by damage done by Christmas feasting; for, so far as we have been able to determine, in other places of similar climate, the winter increase in gastro-intestinal disorders does not, under ordinary circumstances, take place. Moreover, the case is very different in Hamburg in the various years. And above all, it has ceased since the city water has been well filtered (Und vor Allem da sie aufgehört hat, seitdem das Wasser der städtischen Wasserleitung gut filtrirt wird).

The suspicion cast upon the unpurified Elbe water by these facts is strengthened by observations in other places. In this connection what happened in the district of the Stralau waterworks at Berlin[1] is of great interest. When the waterworks delivered badly filtered water, the population of the district supplied from Stralau responded at once with an increased mortality of infants from gastro-intestinal diseases, which occurred moreover exclusively among infants artificially nourished. A similar observation was recorded in the report mentioned (p. 13) regarding the Altona[1] waterworks as early as 1870, and it was further stated that every time disturbances took place in the operation of the filters at the Altona works, the prevalence of gastro-intestinal disorders increased in the city. Finally, it was recounted that after several high tides in November and after an especially high "storm-tide" on the 4th of December, 1892, bringing about a heavy pollution of the Elbe water at the waterworks intake (proved bacteriologically), an increased infant mortality occurred in Hamburg. The bacterial content of the Elbe River water rose at this time from 200–300 per c.c. to 7,500. Such observations led of necessity to the conclusion, that in other years also when similar events took place the polluted city water was to blame. As already stated (p. 50) there is a possibility that filth particles and pathogenic germs emptied into the Elbe with sewage are driven occasionally by the tide upstream, both to the old and the new waterworks intakes. When this happened there undoubtedly followed as a rule a pollution of the public water-supply, until this danger was eliminated by the establishment of sand filtration and the regular stoppage of pumping at high tide. This danger

[1] For fuller accounts of the phenomena at Berlin and Altona see *Jahresb. über die medizinische Statistik des Hamburgischen Staates fur 1892;* translations given above, pp. 494–97.

was not always of the same magnitude, but varied both according to the amount of fresh water coming down, which made difficult or easy the upstream movement of the tide-wave, and also according to the height of the tide-wave coming in from the sea and influenced by wind and weather (pp. 208-9).

Next follows a description of float experiments, by which it was determined how high the tides would have to be, at various stages of the river, to drive water from the outfall of the main trunk sewer upriver to the old and (since 1893) new waterworks intakes, located 6.3 and 8.5 km. upstream, respectively.

Of course the summer months, with their lower river levels, are by far the most dangerous; there appear, however, extraordinary differences in individual years. On the one hand, there are wet summers with proportionately high fresh water stages, and, on the other, dry years in which the level of the river sinks very low in the hot season. There are also mild, rainy winters in which the river remains high, as well as those in which the whole river-basin freezes up and all the precipitation remains lying on the ground as snow, so that the flow of the river becomes very scanty. Hence for our purposes the separate years must be closely studied (p. 210).

Then follow tables which lack of space forbids us to reproduce, showing, for the period of 1877-93, the varying stages of the river and the exceptionally high tides, and the time relations of these two sets of phenomena.

If the data in these tables be now compared with the tabulations of the contemporaneous deaths from gastro-intestinal diseases (p. 220), it appears clear that the dry years, with subnormal river stages in the late summer and fall (1877, 1878, 1883-1887, and 1892) and with numerous unfavorable tides, have been especially characterized by deaths from these diseases; but that in the driest year of all, 1893, the significant rise in deaths which was to be expected did not take place. It must be concluded from this that low river stages and higher prevalence of these diseases are not merely independent parallel consequences of a greater summer heat, for in that case gastro-intestinal disorders would have been worse than ever in 1893; but that since 1893 there has been broken a link in the chain which previously connected summer gastro-intestinal disorders with the low water. And that break has come with the filtration of the drinking water begun in 1893. This is confirmed, moreover, by observations of all subsequent years down to the end of the century, during which the low waters of the autumns of 1895, 1898, and 1900 have had no perceptible influence whatsoever upon gastro-intestinal disorders.

Without doubt, therefore, the summer gastro-intestinal disorders of children have been largely increased by the city water, so long as this was not filtered The process may be pictured as consisting simply in the dissemination of the infective agents in kitchens, on utensils, on bottles, on the hands of mothers and nurses, or in the milk itself, in greater quantities through the water than in other ways. The germs then multiply more or less, according to the cleanliness of the people and the condition of their dwellings and according to the weather, and, in greater or less numbers, are ingested by infants with their food.

The conditions favoring gastro-intestinal disorders in winter are not so clear, altho these also threw suspicion on the water. It is not difficult, in fact, to discover for those winter seasons in which the deaths from gastro-intestinal diseases rose abnormally, storm-tides upon which the blame could be laid; but in our table are found many high tides which apparently had no effect upon these diseases—in particular, all the storm-tides of the autumn equinox. From these a sceptic could derive justification for disputing altogether the connection between polluted water and gastro-intestinal disorders; he could also adduce the fact that before the sewerage of Hamburg and before the introduction of the public water-supply winter increases in gastro-intestinal diseases had appeared, e.g., in 1838 and 1845; and that even after the establishment of filtration, e.g., in March, 1895, there had been observed once more an increase in deaths from these diseases.

On the other hand, we may reply that the winter rises in the '30's and '40's took place in such small numbers that inferences cannot safely be drawn from them. And if any increase of these diseases did in fact take place in those years, that would not prove that the Elbe water was not to blame, for, in fact, before 1848 water was freely taken from the river, which, in former times, may have been badly polluted upstream. . . . .

Neither can the rise of gastro-intestinal diseases in March, 1895, decide the question, if the scant excess of deaths be given due weight, for in those first years of filtration the management of the waterworks still had difficulties, now entirely overcome, to contend with, arising in very cold weather with the cleaning of the filters. It appears, in fact, from reports in my possession on the bacteriological control of the filters in 1895, that in February and March of that year individual filters repeatedly worked imperfectly, so that a few of the infective agents of these diseases may have slipped through. . . . .

On comparing the two tables on page 211 and page 220, it is found that the high stages of the river caused by melting snow [at certain times] did not have the slightest influence on the number of deaths from gastro-intestinal diseases, while in January, 1883, as also in the beginning of the year 1845, the increase of deaths from these diseases coincides with a much swollen river. Before drawing any conclusions from these observations, further experiments must be awaited, and the conditions in other cities be thoroughly compared.

Meanwhile we must be content to have established the fact that the unpurified city water has, until the inception of filtration, contributed heavily to the spread of gastro-intestinal diseases (pp. 210–16). [The italics are ours.]

The decline in infant mortality is of special interest because in this we see a result of the filtration of the drinking water which has exceeded all expectation and has materially enriched our knowledge of the propagation of gastro-intestinal disorders. . . . . If therefore the whole improvement . . . . cannot be ascribed to these diseases and hence to the results of better water, certainly the overwhelming majority of cases also belongs in this category (p. 310).

We quote also the following with reference to the relation between gastro-intestinal disorders and typhoid fever:

Formerly, disturbances in the operation of the filters at the Altona waterworks repeatedly appeared, especially in very cold weather, which made the proper cleaning of the filters difficult or impossible. At such times unfiltered or insufficiently filtered

water entered the distribution system, whereupon the health of the people would react at once with the appearance of cases of gastro-intestinal disorder, a sure sign to the Altona physicians that two to three weeks later typhoid cases would follow (p. 234).

Examples of such outbreaks are given, characterized as sudden in onset, restricted to the Altona district, falling in seasons otherwise unfavorable to typhoid propagation, and as having been completely absent since the improvement of filtration in Altona.

A similar local and explosive typhoid outbreak occurred in Hamburg in 1893 ("Jahresbericht für 1893," p. 55). On a wharf on the south bank of the Elbe, where the laborers were provided, for drinking purposes, with Elbe water purified by a filter of special construction . . . . 100 laborers suddenly fell sick with gastro-intestinal disorder, and 19 of them developed typhoid. Closer investigation revealed the fact that shortly before the outbreak of the sickness the filter had been "cleaned" and that its efficiency had for a while been very much reduced (p. 235).

. . . . Instances from the winter season are much more characteristic, for then the influences of the summer heat have quite ceased. A few are summarized in the table below [Table 3].

[TABLE 3.]

DEATHS FROM GASTRO-INTESTINAL DISEASES AND CASES OF TYPHOID FEVER, BY WEEKS.

	Week Numbers [from Beginning of Each Year].																					
	41	42	43	44	45	46	47	48	49	50	51	52	1	2	3	4	5	6	7	8	9	10
1888–89																						
Gastro-intestinal diseases	28	**57**	31	21	15	10	17	**43**	**46**	36	28	24	17	11	15	10	43	54	**83**	60	21	..
Typhoid fever	42	32	46	**83**	46	54	32	33	46	**92**	**75**	48	41	50	40	30	45	41	55	80	**112**	57
1890																						
Gastro-intestinal diseases	..	..	..	..	..	..	..	..	..	..	..	..	17	24	17	42	**64**	**67**	29	17	12	8
Typhoid fever	..	..	..	..	..	..	..	..	..	..	..	..	34	35	34	28	35	35	**48**	44	43	24

From this it cannot be doubted, keeping in mind the foregoing instances and similar cases elsewhere (e.g., at the Tegel waterworks in Berlin, January to March, 1889 [account already quoted from "Jahresbericht für 1892"]), that typhoid fever and gastro-intestinal diseases are to be attributed to a common vehicle which can only be found in the public water-supply (p. 238).

3. Tuberculosis.

Especially surprising was the improvement [as to phthisis] in the period from the fourth to the sixth decade, when the sewerage and water-supply systems just completed must have been of very strong influence for general cleanliness (p. 285).

In tuberculosis the decline in mortality began long before 1872; but this progressive improvement has gone on at a distinctly brisker rate since the middle of the eighth decade, due no doubt to the fact that after the discovery of the tubercle bacillus the measures already in operation were more systematically applied. At the same time

it is worthy of notice that it is maintained from the surgical side that since the filtration of the water the number of cases of bone and joint tuberculosis has diminished extraordinarily. Further observations should tell whether a causal connection really exists here. At any rate such a possibility cannot be excluded, since of course the sputa and bowel discharges of all the tuberculous reach the Elbe through the sewers, and tubercle bacilli just as well as typhoid bacilli could have been carried thence in the water to the people (p. 309).

4. Other Infectious Diseases.

In reference to "Inflammatory Diseases of the Respiratory Organs" ("Entzündliche Erkrankungen der Atmungsorgane") (not including phthisis):

Unfortunately such a variety of diseases must be included under this title that only a very general orientation is possible (p. 101).

The decline in these diseases since 1893 is very striking. Prior to that time the annual death-rate from these causes was 3 to 4 per thousand inhabitants, but now the mortality has dropped to 2 to 3 per thousand. What has worked this revolution is difficult to determine, as the picture of events [see diagram] is much confused by the large influenza epidemics of 1891, 1895, and 1900 (p. 103).

The conditions with respect to diseases of the respiratory organs (exclusive of tuberculosis) are even more obscure [than for tuberculosis]. Still the striking improvement [shown by comparative rates for the two periods 1872–96 and 1896–1900] in this group, which includes very diverse forms of disease, must be accredited more to general sanitary improvements than to the filtration of the water (p. 310).

It is interesting to note that of all deaths from inflammatory diseases of the respiratory organs in the period 1872–1900, about 25 per cent occurred among infants under one year of age (pp. 133, 160).

In the quotations here given we believe that we have cited all of special interest or importance in reference to the effect of a purified water-supply upon the various infectious diseases in Hamburg. And we desire, on leaving this portion of the subject, to express our high appreciation of the thoroughness of the work of Dr. Reincke and his associates, which has thrown so much light upon this important subject.

VI. MR. MILLS'S FURTHER STUDIES ON THE WATER-SUPPLY AND TOTAL DEATH-RATE, ETC., OF LAWRENCE, MASSACHUSETTS, AND HIS ADDRESS TO THE CITY GOVERNMENT OF LAWRENCE, 1893–1902.

Ever since 1893 Mr. Mills had been making further observations and studies, some of which he had reported to his colleagues on the State Board of Health of Massachusetts as early as 1896. Several

years later (July 3, 1902) in the course of an address before the city government of Lawrence, he read a statement of his results, from which we may quote the following striking paragraphs, published the next day in the Lawrence newspapers:

The deaths from typhoid fever dropped from an average of 52 per year for the six years previous to the use of the filtered water to an average of 12 per year in the past six years. But this is only a small part of what has been accomplished. The deaths from all diseases in the city have, since the filter was built, averaged 19 annually per thousand of inhabitants, while in the six years previous to the building of the filter the deaths from all diseases averaged 24 per 1,000 annually. That is, in the years since you began to use filtered water there has been an average of 300 less deaths per year than there would have been if the death-rate had continued as before. . . . .

When the United States Census Bureau of 1900 found that the deaths in Lawrence were, when they considered the increase in population, equivalent to more than 300 less deaths than in 1890, they wrote to your City Board of Health asking the cause, and were informed that the principal cause that they could indicate was the introduction of filtered water for the use of the city in 1893. They had reason for their conclusion when their records showed the deaths in 1892 to be 1,246 and the deaths of 1894 to be 925; a difference of 321 deaths from the year before to the year after the filter was completed.

Since you began to drink filtered water the records show that there have been as many as 2,500 less deaths in the city than there would have been if the average death-rate of the previous six years had continued to this time; and this has been one of the sources of increase in population. . . .

The decrease in deaths has not been limited to deaths caused by diseases which are known to be conveyed by water, nor to infectious diseases, but includes so broad a range of diseases that we must conclude that the general health of the people has been improved and their ability to resist and overcome disease has increased.

VII. DISCUSSION BY MR. ALLEN HAZEN, C.E., OF THE WATER-SUPPLY OF LAWRENCE IN RELATION TO THE TOTAL DEATH-RATE, 1901.

In the published discussion of a paper[1] presented by Messrs. Morris Knowles and C. G. Hyde at a meeting of the American Society of Civil Engineers, June 5, 1901, Mr. Hazen made the following statement:

While the most striking reduction in the death-rate following the use of filtered water was in typhoid fever, the general death-rate showed a very considerable reduction. Table No. 26 shows the death-rate per thousand living for the seven years that the filter has been in operation, together with the corresponding rates for three preceding periods of seven years each.

The reduction in the general death-rate in the last seven years, as compared with the seven preceding years, is several times as large as the reduction in the typhoid

[1] The Lawrence, Mass., City Filter: A History of Its Installation and Maintenance, *Trans. Am. Soc. C.E.*, 46, p. 316.

fever death-rate, and perhaps indicates the effect of the quality of the water on other diseases. The question as to how far this is due to the water-supply, and how far to improved general sanitary conditions, may be properly raised; but the very decided reduction at the time of the introduction of the filter, and the steadiness with which the rate has continued on a lower level since, seem to indicate that the water-supply had something to do with the reduction, and that the coincidence was not accidental.

VIII. A GRAPHICAL DEMONSTRATION OF THE LAWRENCE PHENOMENA PUBLISHED BY MR. MILLS, 1904.

In April, 1904, Mr. Mills showed to one of the authors (W. T. S.), who was about to give in Lawrence a public address on the water-supply of that city, the diagram herewith reproduced (with addition of recent years by the authors) as Chart 1, and kindly permitted him to make from it a lantern slide which he then used and has since used from time to time in his lectures. This diagram, which was afterward published with slight additions in the Annual Report of the Water Board of Lawrence for 1906, illustrates in a very striking way the Mills-Reincke phenomenon to which we have now repeatedly referred.

IX. FORMULATION OF HAZEN'S THEOREM, 1904.

At the International Engineering Congress held at St. Louis in October of the same year, Mr. Allen Hazen took an important step in advance, and formulated a numerical expression for the comparative effect of water purification upon typhoid fever mortality and total mortality. He had already approximated such an expression in his statement made in 1901 and quoted above that—

the reduction in the general death-rate . . . . is several times as large as the reduction in the typhoid fever death-rate.

On account of its importance as the first attempt, so far as we are aware, to reduce to a quantitative statement the Mills-Reincke phenomenon, we shall quote in detail that part of Mr. Hazen's study which concluded with the formulation as above mentioned of a numerical expression of the relation of total mortality to typhoid fever mortality.

The general death-rate, as might be expected, is also reduced, and it is reduced to a greater extent than can be accounted for in the reduction of the typhoid fever rate. The percentage of reduction in the general death-rate is less than it is with typhoid

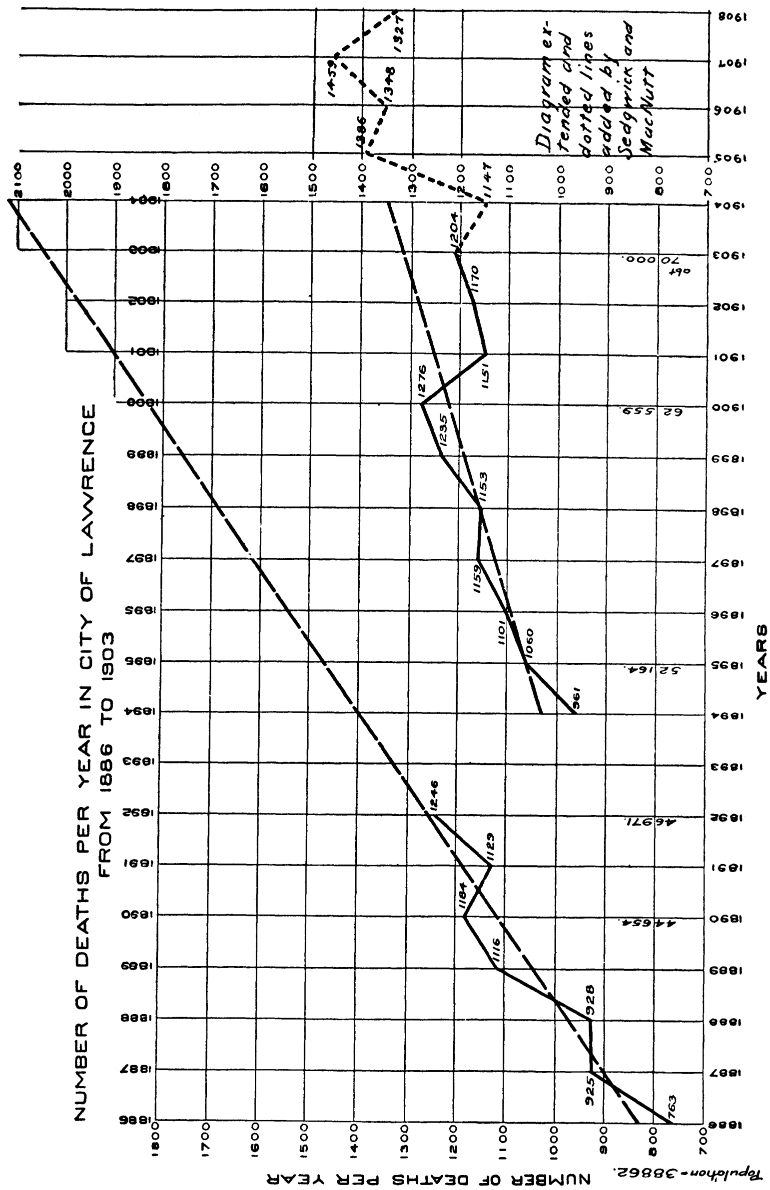
NUMBER OF DEATHS PER YEAR IN CITY OF LAWRENCE
FROM 1886 TO 1903
YEARS
NUMBER OF DEATHS PER YEAR
Population - 38862.
Diagram extended and dotted lines added by Sedgwick and MacNutt

CHART 1.

fever and it is therefore more difficult to follow the relation, and the reduction attributable to the change in water can be ascertained with less certainty.

Tables 5 and 6 show the general death-rates and the death-rates from typhoid fever in a number of cities, before and after radical improvements in their water-supplies. In four cases, two in Europe and two in the United States, the changes were made by the installation of sand filters. In the other cases the changes were from polluted river supplies to upland waters from unpolluted sources, or to ground-water. The year of change (when both the old and new supplies were in use) is omitted in each case. At Lowell, Mass., where the change was more gradual, two years are omitted, and at Hamburg, the cholera year, 1892, which immediately preceded the year in which the filters were put in service, is also omitted from the comparison.

TABLE 5.

DEATHS FROM TYPHOID FEVER PER 100,000 PER ANNUM.

Place	Date of Change	Five Years before Change	Five Years after Change	Percentage of Reduction
Zurich, Switzerland .... Filtration	1885	76	10	87
Hamburg, Germany .... Filtration	1892–93	47	7	85
Lawrence, Mass .... Filtration	1893	121	26	79
Albany, N.Y. .... Filtration	1899	104	28*	73
Lowell, Mass., river water to ground-water	1895–96	97	21	78
Newark, N.J., river water to upland water	1892	70	16	77
Jersey City, N.J., river water to upland water ..	1896	77	24	69
Averages		85	19	78

* Four years.

The reductions in death-rates with the installation of filters have been quite as great as in those cities where the new sources of supply were from unpolluted sources. The average reduction in the typhoid rate was 66 per 100,000. The reduction in the general death-rate was 4.7 per 1,000 or 470 per 100,000.

TABLE 6.

DEATHS FROM ALL CAUSES PER 1,000 PER ANNUM.

Place	Date of Change	Five Years before Change	Five Years after Change	Percentage of Reduction
Hamburg, Germany .... Filtration	1892–93	24.0	17.7	26
Lawrence, Mass .... Filtration	1893	24.4	20.0	18
Albany, N.Y. .... Filtration	1899	22.3	18.4*	17
Newark, N.J., river water to upland water	1892	25.1	22.1	12
Jersey City, N.J., river water to upland water ..	1896	25.4	19.3	24
Lowell, Mass., river water to ground-water	1895–96	25.1	20.5	18
Averages		24.4	19.7	19

* Four years.

While the reduction in the typhoid rate is 66 per 100,000, that in the general death-rate is 4.7 per 1,000 or 470 per 100,000, or seven times as much. Where there is one less death from typhoid fever there are six less from other causes.

The writer believes that the whole of the reduction in the typhoid rate should be attributed to the change in water-supply, because cities similarly situated, which have

not improved their supplies, have experienced no permanent reduction in their typhoid fever rates. With the general death-rate the case is different. Improved general sanitary conditions have reduced the death-rates in recent years, and the normal reduction in a period of six years, which represents the average elapsed time between the first and second series of results, would account for a part of the reduction in the general death-rate.

The average reduction in the general death-rate between 1890 and 1900 in eighteen cities having from 50,000 to 300,000 inhabitants, in New England, New York, and New Jersey, which made no radical change in their water-supplies, was 2.28 per 1,000. This is computed from the Report on Vital Statistics in the United States Census of 1900. Assuming a uniform decrease in rate in the interval, the average, or what we may call the normal, reduction, in 6 years would have been 0.6 of this, or 1.37 per 1,000. In comparison with this, in five cities where the water was radically improved, the reduction in the same period was 4.4 per 1,000. The results may be tabulated as follows:

	Death-Rate per 100,000 Living
Reduction in total death-rate in five cities with the introduction of a pure water-supply	440
Normal reduction due to general improved sanitary conditions, computed from average of cities similarly situated but with no radical change in water-supply	137
Difference, being decrease in death-rate attributable to change in water-supply	303
Of this, the reduction in deaths from typhoid fever was	71
Leaving deaths from other causes attributable to change in water-supply	232

This computation indicates that *where one death from typhoid fever has been avoided by the use of better water, a certain number of deaths, probably two or three, from other causes have been avoided.* [Italics our own.] This seems the clear and logical conclusion from the statistics. It is not easy to explain how the water is connected with the deaths other than those from typhoid fever. It may be that a good water-supply, used freely and with confidence, results in a better general tone in the systems of the population, and so indirectly to a lower death-rate, and that a part of the reduction is represented by diseases having no recognized connection with the quality of the water-supply ("Trans. Am. Soc. C.E.," 54D pp. 151–53).

The quantitative relation thus arrived at by Mr. Hazen and italicized above, seems to us to deserve, because of its far-reaching importance, some special designation. We have therefore ventured to apply to it in our preliminary paper[1] the term *Hazen's Theorem.*

Mr. Hazen further added, in the discussion on this paper:

The writer agrees with Messrs. [E. O.] Jordan and G. W. Fuller that it is most important that further study be made of the effect of water-supply upon other diseases than typhoid fever. The statistics certainly indicate a much wider influence of water-supply upon public health than has been generally admitted; and it would seem as if studies might be made to ascertain the facts more definitely (*ibid.*, p. 251).

[1] *Science*, August 14, 1908.

X. OTHER DATA AND DISCUSSIONS BEARING ON THE GENERAL SUBJECT.

We have not been able to find later than the formulation in 1904 of Hazen's theorem any definite advance in the analysis of the underlying Mills-Reincke phenomenon or any attempt at a general proving of the theorem itself. It enunciation has, however, caused occasional discussion and called forth some confirmatory data from various quarters. Without attempting to quote all such data and discussions we shall summarize the more important.

Professor Edwin O. Jordan, in the discussion on Mr. Hazen's St. Louis paper, made the following remarks:

> Mr. Hazen's computation which indicates that, in addition to the reduction in deaths from typhoid fever, there occurs a similar reduction in deaths from other causes, and that this also is attributable to a change in the water-supply, is certainly very striking. There is one suggestion which the writer would like to offer concerning a possible explanation of this circumstance.
>
> It is well known that the obscure character and variable symptoms of certain cases of typhoid fever lead not uncommonly to a mistaken diagnosis. There is no doubt that in every considerable body of vital statistics some cases of genuine typhoid fever are reported under other names. It need hardly be said that this is particularly true as regards the deaths reported under the captions "typho-malarial fever," "malarial fever," and similar designations. In the Northern United States, the majority of the deaths reported under these headings are deaths from typhoid fever. The effect of filtration well illustrates this point. In the city of Albany, N.Y., there were 37 deaths reported under the heading "malarial diseases" in the four years, 1891–94, and 23 deaths in the four years, 1895–98, while for the four years following filtration (1900–1903), there were but two deaths under the same head.
>
> It must be remembered also that a marked improvement in methods of diagnosis of typhoid fever has taken place during the last decade. One result of this has been that deaths formerly reported as occurring from other causes are now correctly reported as due to typhoid fever. This transfer to the column of typhoid deaths naturally diminishes the deaths reported from general causes and must, at least, partly explain the relation pointed out by Mr. Hazen. It may also serve to explain why the apparent reduction in deaths from typhoid fever is sometimes less than would be reasonably anticipated. The suggestive facts brought out in the paper indicate that other items under the reported deaths in official health reports might repay examination ("Trans. Am. Soc. C.E.," 54D, pp. 206, 207).

Three years later the phenomenon observed at Lawrence by Mr. Mills was referred to in a paper[1] by Mr. H. W. Clark, who called attention to a similar decline following the introduction of filtration at Albany, N.Y.

[1] *Monthly Bull. Mass. State Board of Health*, Sept., 1907, p. 242.

On November 6, 1907, Mr. Edward E. Wall, in a paper[1] presented before the American Society of Civil Engineers, wrote as follows:

Allen Hazen, M. Am. Soc. C.E., estimates that where one death from typhoid has been avoided through an improved water-supply probably two or three deaths from other diseases have been avoided. The following record seems to indicate a higher proportion of decrease than Mr. Hazen's estimate would give:

ANNUAL MORTALITY RECORD, ST. LOUIS, MO., 1900–1906, FROM DISEASE ALONE.
[Chemical precipitation introduced in 1904.]

1900	9,217	1904	10,695
1901	9,916	1905	9,545
1902	9,654	1906	9,214
1903	10,320		

Mr. Mills's observation of the phenomenon at Lawrence was again referred to by Mr. Stephen DeM. Gage in the discussion on a paper on filter operations at Lawrence, Mass., presented by Messrs. M. Knowles, M. F. Collins, and A. D. Marble before the New England Water Works Association, February 12, 1908:

In addition a very material reduction has occurred in the total death-rate of the city, a reduction so different in character from that gradual decrease due to increased appreciation of municipal sanitation which has taken place throughout the State of Massachusetts and following so closely the introduction of filtered water that it can only be explained by attributing it to the improvement in water-supply ("Jour. N.E. Water Works Assn.," 22, p. 232).

Mr. Gage accompanied his statements with a diagram showing the decline in the typhoid fever death-rate and in the total death-rate at Lawrence for the period 1880–1905.

Finally, as the only other reference we have been able to discover, we may record the observation based on statistics, by Mr. E. L. Grimes, City Engineer of Troy, N.Y., and reported at the same meeting, that following the extension and sanitary improvement of the water-supply of that city there occurred a distinct decrease, not only in the deaths from typhoid fever, but also in the deaths from cholera infantum, diarrhea, diseases of the digestive organs, and of children under five years of age.[2]

XI. A RECAPITULATION OF THE LITERATURE, AND A BRIEF OUTLINE OF THE WORK OF THE AUTHORS.

A review of the foregoing sections leads irresistibly to the conclusion that Messrs. Mills, Reincke, and Hazen, in their observations

[1] "Water Purification at St. Louis, Mo.," *Trans. Am. Soc. C.E.*, 60, p. 182.

[2] *Jour. N.E. Water Works Assn.*, 22, p. 183.

and studies already described, have brought to light phenomena of the very first importance in sanitary science. There appears to be no escape from the conclusion that the purification of polluted public water-supplies reduces the general death-rate much more than it would be reduced by the saving of deaths from the commonly recognized water-borne diseases, typhoid fever and Asiatic cholera, alone. The question naturally arises, to what extent is the general death-rate reduced? And this simple question Hazen's theorem undertakes to answer. Another question which naturally arises is, in what particular diseases does this reduction take place? And this question we shall ourselves undertake to answer.

As yet very few students of public health science are aware of the extent of the studies of Reincke and Mills; and no one, so far as we know, has hitherto undertaken any thorough confirmation of their results. We have therefore ventured to make a study of this kind, first critically examining all the evidence in our possession relating to the Mills-Reincke phenomenon and Hazen's theorem; and then, having found the latter sound and conservative, passing on to the study of fresh examples, to test its scope and range.

Following the historical development of the subject we have naturally begun with the data afforded by the city of Hamburg.

XII. A GRAPHICAL DEMONSTRATION AND DISCUSSION, BY THE AUTHORS, OF THE HAMBURG PHENOMENA.

As a detailed demonstration of the mortality phenomena before and after the introduction of filtration at Hamburg we have taken statistics from the "Sanitary History of Hamburg in the Nineteenth Century" and plotted from them in Chart 2 the curves for certain important causes of death. On the vertical lines, corresponding to the middle of each year, are plotted the average annual death-rates. The period of unfiltered water is indicated by the heavy black bars beginning on the left and crossing more than one-half the diagram. The period of filtered water-supply is indicated by the clear spaces following these heavy black bars. The scale employed, it must be observed, is the same for all the curves except the two lowest, thus facilitating comparisons. In order to save space, the unused portion of the scale below each curve except the uppermost has been cut off.

Hamburg is well known in the annals of sanitary science on account of its great Asiatic cholera epidemic of 1892. A slow sand filter was at that time in process of construction, and the epidemic of cholera caused a precipitate activity in construction which resulted in the rapid completion of the filter and the beginning of its operation in May, 1893. A brief description of the water-supplies of Hamburg and the neighboring city of Altona is given by Dr. Reincke in his Annual Report for 1892 and translated by Mr. Hazen in an appendix to his "Filtration of Public Water-Supplies." A fuller account is given in the "Sanitary History of Hamburg in the Nineteenth Century." We need only recall that previous to the introduction of filtration in Hamburg the public water-supply was taken from the (tidal) Elbe River at a point about four miles above the outfalls of the main trunk sewers of Hamburg and Altona. In 1893 the intake was moved about a mile farther upstream, and while the river at these points was probably not ordinarily heavily polluted, Dr. Reincke brings conclusive evidence (quoted by us, pp. 495–97, 500–503) to show that at certain times of high tide and low river the sewage of Hamburg and Altona was driven upstream and came at such times directly to both intake points. By filtration the effects of the pollution from this source have been eliminated. As the diagrams of death-rates in Chart 2 speak for themselves, we need comment on them only briefly.

From the first curve it will be seen that the typhoid fever death-rate fell from an average of about 30 in the five years prior to 1893 to a rate after filtration of less than 10 per 100,000.

In inflammatory diseases of the respiratory organs there was an extraordinary drop, and the rates from this cause of death have continued on a much lower level since 1893. The fall in the mortality from these diseases is so striking that we have continued the computation of the rates for a few years beyond the last date shown in the plate, and have found that the low level assumed after introduction of filtration was steadily maintained. The following rates are computed from data from the Imperial Health Office Bulletin, "Sterbefälle im Deutschen Reiche"; for 1901, 228; 1902, 215; 1903, 196; 1904, 188; and may readily be added by the reader if he so desires. (To avoid misunderstanding of the method of plotting

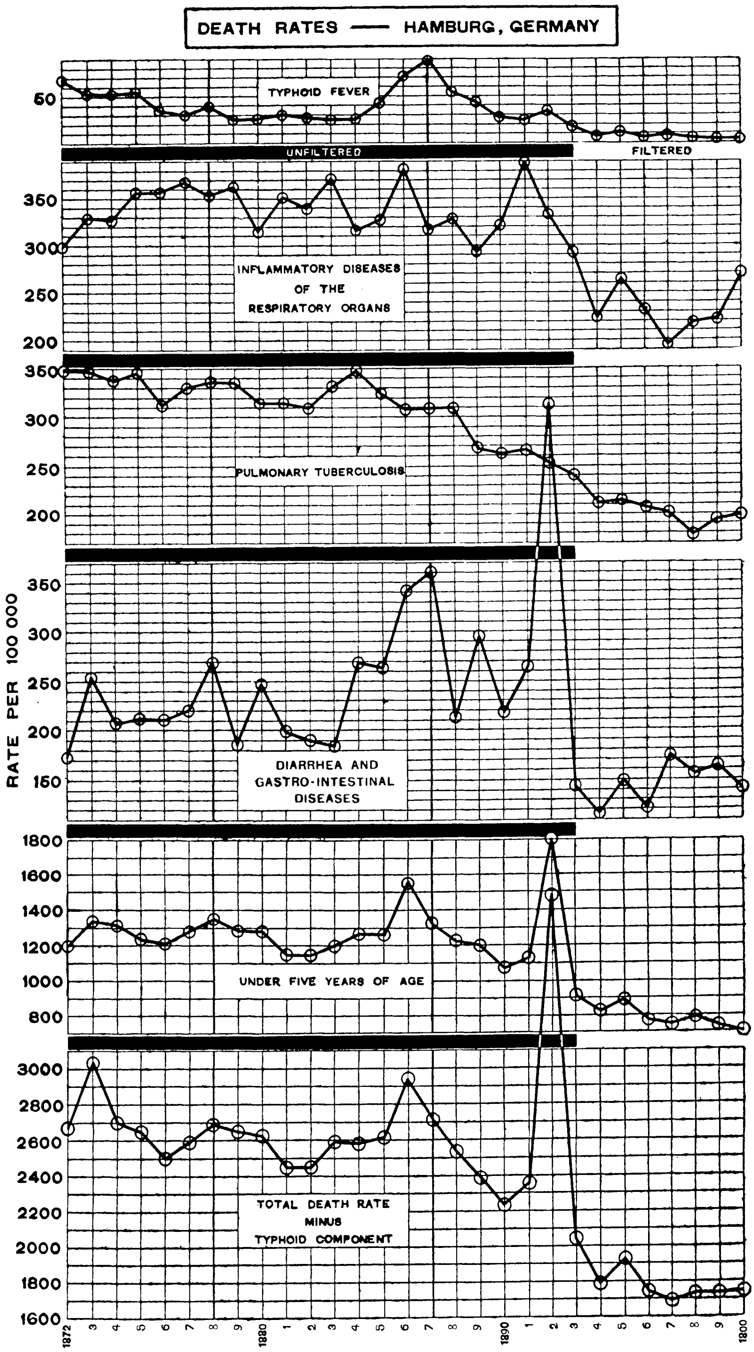
DEATH RATES —— HAMBURG, GERMANY
TYPHOID FEVER
UNFILTERED
FILTERED
INFLAMMATORY DISEASES OF THE RESPIRATORY ORGANS
PULMONARY TUBERCULOSIS
DIARRHEA AND GASTRO-INTESTINAL DISEASES
UNDER FIVE YEARS OF AGE
TOTAL DEATH RATE MINUS TYPHOID COMPONENT
RATE PER 100 000
50
350
300
250
200
1800
1600
1400
1200
1000
800
3000
2800
2600
2400
2200
2000
1872
1880
1890
1800

CHART 2.

we must again caution the reader that the unused scale below this, as below subsequent curves, has been cut off.)

Pulmonary tuberculosis, which had been gradually declining for ten years, showed a somewhat greater rate of decline for the year following the introduction of filtration. Whether the purification of the water-supply played any considerable part in this we are unable, from the Hamburg data alone, to determine, but our studies in later sections of this paper on Lawrence and Lowell, Massachusetts, give good reason for supposing that at Hamburg also the purification of the water-supply had a certain effect in lowering the mortality from phthisis.

The title "diarrhea and gastro-intestinal diseases," as used in Chart 2, corresponds to the German *Durchfall und Brechdurchfall.*[1] The curve for this cause of death shows very strikingly the influence of the change to a purified water-supply. From an average rate immediately before filtration of about 300 it dropped suddenly by a full half, at which level it has since continued to 1900. We are forcibly reminded of Dr. Reincke's remark, already quoted, that "in no other diseases did the favorable influence of the better water-supply introduced in 1893 stand out so clearly as in these."

The curve for the death-rate of children under five years of age shows a similarity to that for diarrhea and gastro-intestinal diseases, including as it does a large number of deaths from the latter. Thus the drop in 1894 and the continued lower level of subsequent years is seen in a degree which, when the difference of the scales is taken into account, is as striking here as in the curve just above. A considerable share of this mortality is also contributed by inflammatory diseases of the respiratory organs, and a certain similarity between the two curves may readily be traced. We again call attention to the fact that the scale in this diagram, like all the others in the chart except the topmost, is not extended fully to the true base line.

Finally, the diagram for total death-rate minus typhoid component illustrates strikingly that drop following the introduction of filtration which we have named the Mills-Reincke phenomenon, as observed at Hamburg by Reincke. It is at once seen how sudden, how great, and how permanent was the reduction in this death-rate.

[1] See note, p. 494.

The rate had reached a miminum in 1900, and was on its way up again when the influence of filtration came into play. How great numerically the reduction actually was, and how far it is to be attributed to the purification of the water-supply, is discussed below.

In order to carry the graphical demonstration still farther, we have plotted in Chart 3 the death-rates for age-groups, which rates are reckoned more accurately—on the population in each age-group—than on the total population. The Mills-Reincke phenomenon is here seen to affect all age-groups—that under one year, however, most notably. This is evidently to be accounted for very largely by the relation of water-supply to diarrheal and gastro-intestinal diseases, as explained by Dr. Reincke (secs. iv and v), 90 per cent of these diseases having occurred among infants under one year of age and constituting about one-quarter of the whole mortality of the latter.

Thus from Charts 2 and 3 it is seen that all of Dr. Reincke's statements on the decline in total death-rate, in infant mortality, and in the other diseases mentioned by him are fully substantiated. More than that, the data afford a basis for going somewhat beyond his statements, which, as we shall show, were characterized by much caution.

It may be objected that there were, possibly, at the time under consideration, declines in the total death-rates of German cities in general; in order, therefore, to show the extraordinary character of the drop at Hamburg we present the table on p. 519 for the ten largest cities of Germany (according to the Census of 1890), showing their average total death-rates for two periods of three years each, before and after the cholera years and introduction of filtration at Hamburg, the corresponding typhoid fever rates also being given.

It is at once evident how remarkable the reductions were at Hamburg, both in typhoid fever and in the total death-rate. Taking the typhoid fever rate as an index of quality of water-supply, Hamburg is shown to have been much worse off than any other city during the first period. In the second period all show declines, but that in Hamburg stands far above them all, having been six times as great as the average

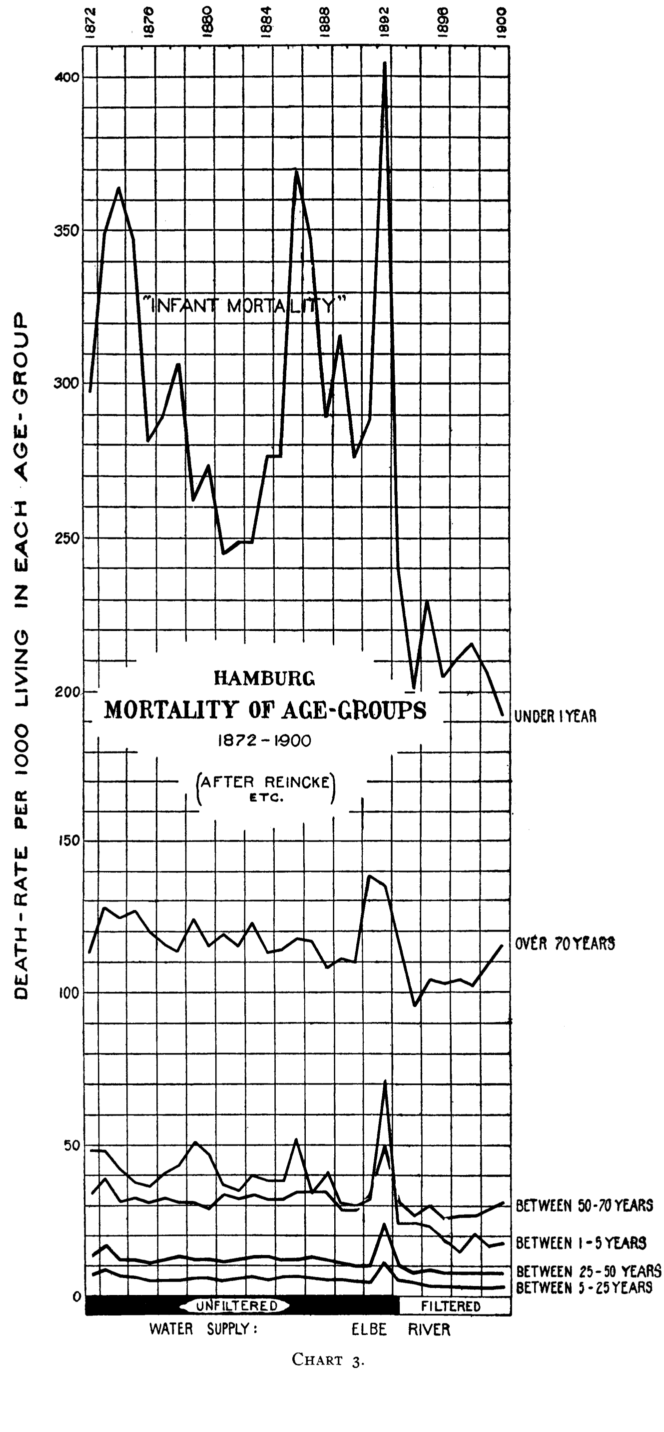
HAMBURG
MORTALITY OF AGE-GROUPS
1872 - 1900
(AFTER REINCKE ETC.)
"INFANT MORTALITY"
DEATH-RATE PER 1000 LIVING IN EACH AGE-GROUP
1872
1876
1880
1884
1888
1892
1896
1900
400
350
300
250
200
150
100
50
0
UNDER 1 YEAR
OVER 70 YEARS
BETWEEN 50-70 YEARS
BETWEEN 1-5 YEARS
BETWEEN 25-50 YEARS
BETWEEN 5-25 YEARS
UNFILTERED
FILTERED
WATER SUPPLY: ELBE RIVER

CHART 3.

for the other nine cities. In total death-rate the drop at Hamburg is much greater than that of any other city, and over four times as great as that of the other nine, and this over and above the results of sanitary improvements going on in the other cities.

TABLE 4.

TEN LARGEST GERMAN CITIES	TYPHOID FEVER DEATH-RATES PER 100,000			TOTAL DEATH-RATES PER 1,000		
	1889–91 incl.	1894–96 incl.	Decrease	1889–91 incl.	1894–96 incl.	Decrease
1. Berlin	13	5	8	21.8	20.0	1.8
2. **Hamburg**	**31**	**7**	**24**	**23.1**	**19.2**	**3.9**
3. Munich	8	3	5	27.6	25.2	2.4
4. Breslau	12	8	4	28.8	27.3	1.5
5. Leipzig	13	9	4	20.0	21.7	−1.7
6. Cologne	13	7	6	25.8	24.1	1.7
7. Dresden	8	6	2	20.8	21.0	−0.2
8. Magdeburg	20	9	11	24.6	23.7	0.9
9. Frankfort-on-the Main	8	5	3	18.9	17.6	1.3
10. Hanover	8	7	1	19.6	19.3	0.3
Nine cities exclusive of Hamburg (average)	11	7	4	23.1	22.2	0.9

Typhoid fever death-rates, with exception of Magdeburg, from G. C. Whipple's "Typhoid Fever," App. XVI; other death-rates computed from "Statistisches Handbuch deutscher Städte." The Hamburg figures refer to the *Stadt* exclusive of suburbs, and hence do not quite agree with the rates given by Dr. Reincke for the whole Hamburg district (*Staat*).

Several questions naturally arise at this point. How great was the reduction at Hamburg, not only in the total death-rate, but also in the specific diseases? And what causes contributed most to the total reduction? In answer to these questions we submit in the table on p. 520 a statistical synopsis which we have made of the Hamburg phenomena. The cholera year (1892) and year of introduction of filtration (1893) are omitted, and the means of five years before and five years after are computed, so as to be comparable with our studies of Lawrence and Lowell in sec. xvi.

Of the total reduction, i.e., in the general death-rate, we find that the chief components for specific causes of death are as follows: 19 per cent contributed by diarrhea and gastro-intestinal diseases; 15 per cent by inflammatory diseases of the respiratory organs; 12 per cent by phthisis; 8 per cent by diphtheria; 6 per cent by typhoid fever; and 40 per cent by other causes of death. Viewing the total reduction from the standpoint of age of decedents, we find that 38 per cent falls in the infant mortality under one year of age (as reckoned on the total population).

For every death less from typhoid fever after filtration there were 15.8 deaths less from other causes, but as this figure is merely crude—i.e., has not been corrected for the decrease in mortality that would have taken place independently of water-supply purification—it cannot properly be substituted as the numerical member of Hazen's theorem (see p. 510). It is, however, so much greater than the figure suggested by Mr. Hazen that we are led to venture a partial explanation in the fact that there was not as much typhoid fever to begin with at Hamburg as at Lawrence and Lowell, whether the periods before or after filtration be compared; so that typhoid fever played a smaller part, in proportion, at Hamburg, than in the two American cities upon which, among others, Mr. Hazen's estimate was based.

TABLE 5.

DEATH-RATES, GENERAL AND SPECIFIC, IN HAMBURG BEFORE AND AFTER ADOPTION OF FILTRATION.
Computed from the "Sanitary History of Hambuig in the Nineteenth Century."

Cause of Death	Mean Death-Rate 1887–91 Incl.*	Mean Death-Rate 1894–98 Incl.*	Percentage Decrease
All causes	2444	1,774	27
Asiatic cholera	No deaths	except in 1892 and	1893
Typhoid fever	47	7	85
†Diarrhea and gastro-intestinal diseases	270	143	47
†Infant mortality (under 1 year)	304	213	30
Inflammatory diseases of the respiratory organs	329	226	31
Phthisis	283	202	29

* Rates are per 100,000 of population except in the case of infant mortality, for which they are reckoned per 1,000 living under one year of age.

† These two titles overlap; one-quarter of the "infant mortality" is due to "diarrhea," and nine-tenths of the deaths from the latter fall under "infant mortality."

To sum up the Hamburg phenomena, we return again to the striking demonstration of the Mills-Reincke phenomenon as observed there by Dr. Reincke. This consisted in a sudden and permanent drop in the total death-rate minus typhoid component in 1893, an effect observable even in the rate for that year. The whole trend since 1872 of all the curves which we have exhibited, with the exception of that for pulmonary tuberculosis, was changed, each one pitching rapidly and immediately downward and assuming a distinctly lower level thereafter. We refer again to Dr. Reincke's comments on these phenomena as summarized in the preceding pages. We may here anticipate, and say that after our studies on other cities set forth in the following sections, we shall be forced to conclude that—except in respect to

diarrhea and gastro-intestinal diseases and the recognized water-borne diseases, typhoid fever and Asiatic cholera—Dr. Reincke attributed to the purification of the public water-supply much less than its true share in the remarkable reduction in the total and specific death-rates of Hamburg.

XIII. GRAPHICAL DEMONSTRATION AND DISCUSSION OF THE LAWRENCE PHENOMENA

We have made a careful study of the vital statistics of the city of Lawrence, where the Mills-Reincke phenomenon was first observed by Mr. Mills, following the introduction of filtration in 1893. In addition to Lawrence we have taken Lowell, Mass., where the public water-supply was also purified about the same time by a different method, i.e., substitution of unpolluted ground-water for polluted river water. Finally, we have taken the city of Manchester, N.H., as being in every important respect similar (as we shall show) to the two cities just mentioned and therefore an excellent norm for comparison. For all of these cities accurate vital statistics are fortunately obtainable. We have based our computations upon substantial foundations, viz., the populations given by the U.S. Census for 1880, 1890, and 1900, and the Massachusetts State Census for 1885, 1895, and 1905, computing the populations for the intermediate years by the "arithmetical" method of the U.S. Census.[1] The possibility of important errors arising from this method of computing populations for intercensal years will be discussed in section xviii.

The cities of Lawrence, Lowell, and Manchester, all manufacturing cities devoted chiefly to textile industries, are situated in the valley of the Merrimac River, a large, swift stream draining a considerable portion of southern New Hampshire and northern Massachusetts. The first two cities are especially well known through the studies on typhoid fever made there by the Massachusetts State Board of Health, and published in the Report of the Board for 1892. The three cities are so similar in size, character of population, industry, and climatic conditions, that they are particularly favorable for purposes of sanitary comparison. Three cities more similar in almost every respect could hardly be found elsewhere. In one important

[1] The merit of this method as compared with certain others in vogue is discussed in Twelfth Census, *Bull. No. 135*, "Methods of Estimating Population."

particular, however, they have differed—viz., in their water-supplies —and, as we shall see below, this fact, in connection with their close similarity in other respects makes their experience almost equivalent to a laboratory experiment. Lawrence, previous to

TABLE 6.

TOTAL DEATHS, DEATHS FROM CERTAIN DISEASES, AND POPULATION, LAWRENCE, MASS., 1883 TO 1905 INCLUSIVE.*

Year	Population	Total Deaths	Typhoid Fever	Pneumonia	Bronchitis	Pulmonary Tuberculosis	Cholera Infantum	Diphtheria and Croup	Apoplexy	Inanition, Marasmus, and Infantile Debility	Heart Disease	Old Age	Diseases of the Kidneys
Merrimac River, unpurified:													
1880	†39,151												
1883	38,978	850	28	60	9	147	57						
1884	38,919	892	19	68	13	142	73						
1885	†38,862	774	17	67	17	163	44						
1886	40,020	763	23	45	14	125	55						
1887	41,178	925	47	74	17	132	71						
1888	42,337	928	48	95	16	134	77	11	17	42	54	29	13
1889	43,495	1,116	55	75	10	110	96	170	23	52	65	17	14
1890	†44,654	1,184	60	117	28	114	96	78	19	74	58	14	20
1891	46,156	1,129	55	133	30	91	101	50	34	69	61	13	24
1892	47,658	1,246	50	156	27	95	130	28	30	94	43	20	10
Change: **1893**	49,160	1,184	39	161	15	113	102	23	29	65	38	23	21
Water-supply, filtered:													
1894	50,662	961	25	88	17	88	101	16	34	56	46	23	17
1895	†52,164	1,060	18	109	23	113	100	14	29	Not	give	n	
1896	54,243	1,101	14	127	32	105	103	25	40	47	62	20	20
1897	56,322	1,159	14	138	26	93	124	47	27	52	73	19	19
1898	58,401	1,153	14	86	30	101	119	63	39	64	82	18	22
1899	60,480	1,235	21	119	36	123	111	64	35	87	87	19	25
1900	†62,559	1,276	13	138	43	116	147	35	34	48	102	19	37
1901	64,057	1,151	13	126	34	108	‡	17	40	44	103	12	23
1902	65,555	1,170	15	169	47	107	‡	12	49	32	87	8	21
1903	67,054	1,226	23	127	36	117	‡						
1904	68,552	1,147	11	159	31	111	‡						
1905	†70,050	1,386	15	203	39	107	‡						

* From Massachusetts State Registration Reports, except last four columns, which are from Reports of Lawrence Board of Health. For certain of the less important causes only the period 1888–1902 inclusive has been taken, the spaces for the remaining years being left blank. Total deaths in this and subsequent Tables 9 and 12 are exclusive of stillbirths.

† Census years. U.S. Census on the even decades; State Census at the intermediate fifth year. Other populations interpolated by the "arithmetical" method.

‡ Title discontinued in State Reports.

1893, had taken its water-supply directly from the polluted Merrimac River only nine miles below the sewers of Lowell, but introduced in that year slow sand filtration; Lowell changed in the years 1894 and 1895 from the same polluted river to a pure ground-water; while Manchester had, throughout the period which we shall consider a surface-water supply of good quality.

The statistics for Lawrence for the period which we have studied are given in Tables 6 and 7.

From these figures we have plotted upon diagrams shown in Chart 4 the death-rates from various causes in Lawrence from 1883–1895 inclusive—a period, that is to say, including the year of the sudden change from an unfiltered to a filtered water-supply, and covering the 10 years before, and 12 years after, that event.

TABLE 7.

TOTAL DEATH-RATES, AND DEATH-RATES FROM CERTAIN DISEASES, LAWRENCE, MASS., 1883 TO 1905 INCLUSIVE, PER 100,000 OF POPULATION.*

Year	Total Death-Rate	Typhoid Fever	Pneumonia	Bronchitis	Pulmonary Tuberculosis	Cholera Infantum	Diphtheria and Croup	Apoplexy	Inanition, Marasmus, and Infantile Debility	Heart Disease	Old Age	Diseases of the Kidneys
Merrimac River, unpurified:												
1883	2,181	72	154	23	377	146						
1884	2,292	49	175	33	365	188						
1885	1,992	44	172	44	419	113						
1886	1,907	58	112	35	312	137						
1887	2,246	114	180	41	320	172						
1888	2,192	113	224	38	317	182	26	40	99	128	69	31
1889	2,566	126	172	23	253	221	391	53	120	149	39	32
1890	2,652	134	262	63	255	215	175	43	166	130	31	45
1891	2,444	119	288	65	197	219	108	74	149	132	28	52
1892	2,614	105	327	57	199	273	59	63	197	90	42	21
Change: **1893**	2,408	79	328	31	230	208	47	59	132	77	47	43
Water-supply filtered:												
1894	1,897	49	174	34	174	199	32	67	111	91	45	34
1895	2,032	35	209	44	217	192	27	56	...	...	..	..
1896	2,030	26	234	59	194	190	46	74	87	114	37	37
1897	2,058	25	245	46	165	220	84	48	92	130	34	34
1898	1,974	24	147	51	173	204	108	67	110	141	31	38
1899	2,042	35	197	60	203	184	106	58	144	144	31	41
1900	2,040	21	221	69	185	235	56	54	77	163	30	59
1901	1,797	20	197	53	169	†	27	62	69	161	19	36
1902	1,785	23	258	72	163	†	18	75	49	133	12	32
1903	1,828	34	190	54	175	†						
1904	1,673	16	232	45	162	†						
1905	1,979	21	290	56	153	†						

* Computed from preceding table.

† Title discontinued in reports. Slow sand filter went into operation September, 1893.

The method of plotting is the same as that in the chart for Hamburg, the vertical lines upon which the rates are plotted representing the middle of each year, and the period of the use of unfiltered Merrimac River water being shown by a black bar running to September, 1893, when filtration was introduced. The scale employed is the same for all curves except the lowest; and, in order to save space,

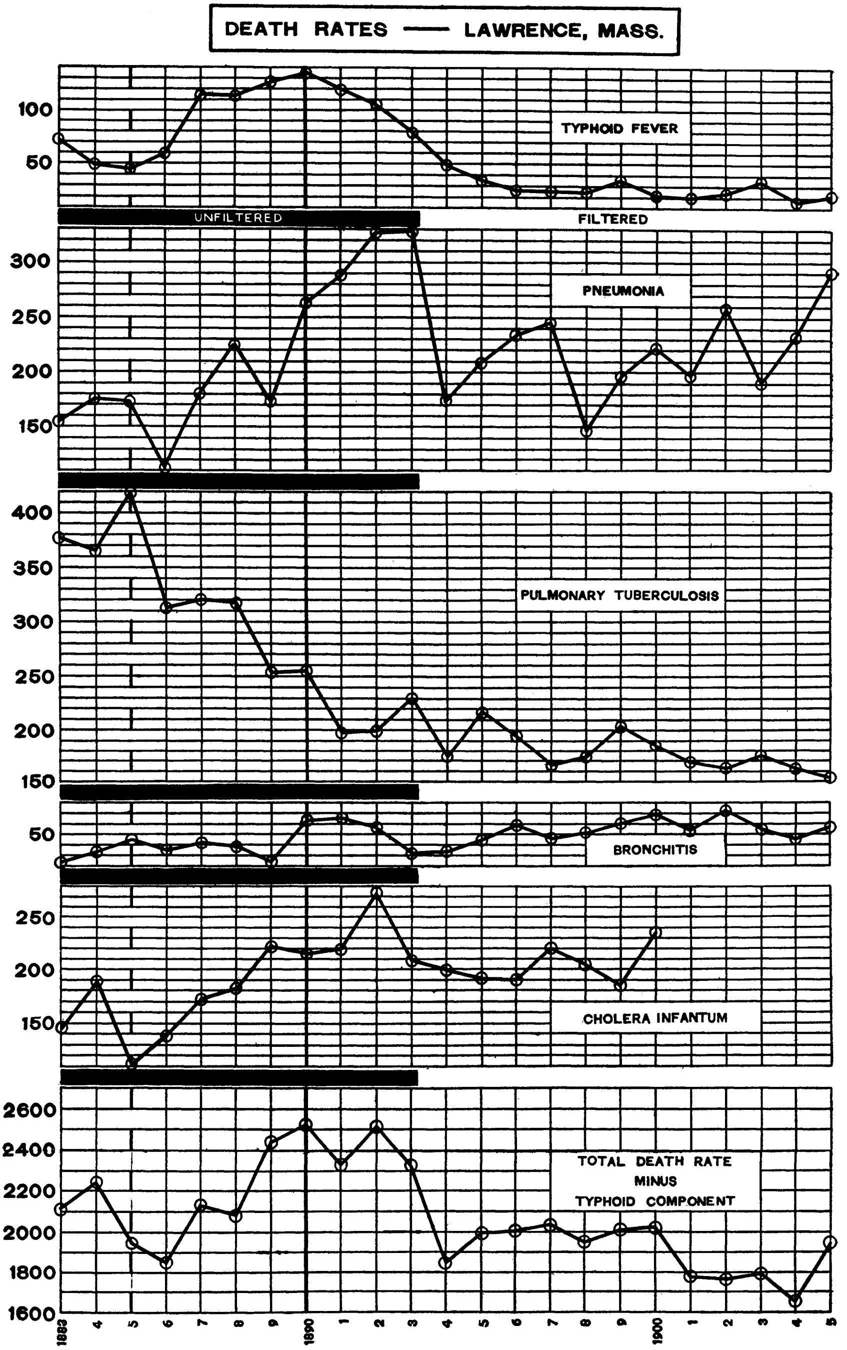
DEATH RATES — LAWRENCE, MASS.
TYPHOID FEVER
UNFILTERED
FILTERED
PNEUMONIA
PULMONARY TUBERCULOSIS
BRONCHITIS
CHOLERA INFANTUM
TOTAL DEATH RATE
MINUS
TYPHOID COMPONENT
100
50
300
250
200
150
400
350
300
250
200
150
50
250
200
150
2600
2400
2200
2000
1800
1600
1883
4
5
6
7
8
9
1890
1
2
3
4
5
6
7
8
9
1900
1
2
3
4
5

CHART 4.

the unused portion of the scale below each curve has been cut off, so that no base-lines are shown.

If we now proceed to analyze the different curves, we find that typhoid fever, which reached epidemic proportions of large magnitude in 1890, declined even before the introduction of the filter, as might naturally have been expected; but immediately afterward sank lower than for many years, and has since remained on a comparatively low level.

The curve for pneumonia is particularly interesting and striking, for it shows that this disease previous to 1893 had been rising by leaps and bounds most of the time since 1885, and had reached very large proportions in 1893. With the introduction of a purer water-supply pneumonia immediately fell back to a point lower than it had shown since 1889; and, altho it rose again somewhat, remained on a comparatively low average for the next 10 years.

Pulmonary tuberculosis was falling rapidly prior to the introduction of filtration, and continued to fall, tho more slowly, afterward. Altho in the curve any decline in phthisis consequent on water purification is so obscured by the effect of improvement in all sorts of other sanitary conditions that it cannot be directly demonstrated, nevertheless, as we showed in our paper entitled "An Apparent Connection between Polluted Public Water-Supplies and the Mortality from Pulmonary Tuberculosis" (referred to above, p. 491), a distinct effect of the filtration of the water-supply appears in this disease also. The evidence upon which this conclusion is based—as will be seen by reference to the above-mentioned paper, or to sec. xvi of the present paper where the same data are presented—is drawn from an analytical comparison with Manchester (*vide supra*) as a norm.

The curve for bronchitis shows no noteworthy phenomena beyond the lowness of the rates for 1893, 1894, and 1895 as compared with the three years next preceding. For this disease also a comparison with some other city such as Manchester as a control is required and is given beyond.

Cholera infantum, which was quite high for several years before the introduction of filtration, was somewhat lower for a number of years afterward.

When we come to the curve at the bottom of the chart we find a striking demonstration of the Mills-Reincke phenomenon. For we see that during the four years previous to the introduction of filtration the total death-rate had been very high, sometimes a little exceeding and sometimes falling a little below 24 per 1,000, a figure of notable height even if all the typhoid fever deaths had been included. Neglecting the year 1893, inasmuch as this was a year characterized partly by polluted and partly by purified water-supply, and beginning with 1894, we observe a most remarkable and extraordinary drop, a drop all the more surprising and convincing since the death-rate here shown is that from diseases and causes of death other than typhoid fever. This curve shows apparently even more clearly than does the typhoid fever curve itself at the top of the chart the striking effect of the purification of the public water-supply.

XIV. GRAPHICAL DEMONSTRATION AND DISCUSSION OF THE LOWELL PHENOMENA

We now present a graphical demonstration of the phenomena at Lowell, based upon statistics which have the same secure foundation as those for Lawrence.

This city, 28 miles below Manchester, and 12 miles below Nashua, N.H., both the latter cities and several others at greater distances discharging their sewage into the Merrimac River, used the polluted river water without purification until 1893. In that year deep wells were driven and the new water was introduced into the city mains along with the old. The supply of ground-water was gradually increased until 1896, when the river water was entirely shut off. The following table shows the progress of the substitution of pure water for polluted:

TABLE 8.
AVERAGE CONSUMPTION OF RIVER WATER AND OF GROUND-WATER IN LOWELL.*

Year	Total Consumption (Million Gals. per Day)	River Water (Percentage of Total)	Ground-Water (Percentage of Total)
1892	...	100	0
1893	6.8	91	9
1894	6.6	65	35
1895	7.0	33	67
1896	7.0	4	96
1897	...	0	100

* Computed from diagram in *Annual Report of Lowell Water Board, for 1896.* The first well water was pumped September 16, 1893. The river water was finally shut off February 22, 1896. Thus 1893 was essentially the last year of the old supply, and 1896 the first year of the new.

The statistics upon which we have based our studies of Lowell are presented in Tables 9 and 10.

TABLE 9.

TOTAL DEATHS, DEATHS FROM CERTAIN DISEASES, AND POPULATION, LOWELL, MASS., 1883 TO 1905 INCLUSIVE.*

Year	Population	Total Deaths	Typhoid Fever	Pneumonia	Bronchitis	Pulmonary Tuberculosis	Cholera Infantum	Diphtheria and Croup	Apoplexy	Inanition, Marasmus, and Infantile Debility	Heart Disease	Old Age	Diseases of the Kidneys
Merrimac River, unpurified:													
1880	†59,475												
1883	62,253	1,432	49	103	35	249	125						
1884	63,179	1,400	41	114	43	206	136						
1885	†64,107	1,329	49	85	26	196	126						
1886	66,824	1,499	50	106	33	191	165						
1887	69,542	1,869	90	168	64	232	157						
1888	72,260	1,763	62	154	61	190	183	107	34	159	102	31	50
1889	74,978	1,897	69	145	73	213	215	101	39	159	141	55	46
1890	†77,696	1,960	125	145	96	214	218	41	42	164	148	66	56
1891	79,030	1,975	78	187	96	222	251	16	44	155	156	61	66
1892	80,364	2,229	77	215	114	231	229	28	51	231	140	56	64
Years of change:													
1893	81,698	2,108	55	217	126	212	286	36	52	216	128	69	54
1894	83,032	1,790	51	137	90	188	221	36	37	146	123	51	47
1895	†84,367	1,869	33	155	78	160	218	52	59	142	154	62	62
1896	86,487	1,922	38	157	86	185	221	46	51	149	153	68	64
Ground-water:													
1897	88,607	1,860	17	170	107	180	177	40	67	133	158	46	46
1898	90,727	1,809	25	165	100	188	185	37	62	115	163	49	91
1899	92,848	1,851	18	197	75	194	179	41	63	112	156	22	54
1900	†94,969	1,850	19	208	86	181	132	27	77	137	190	40	73
1901	94,953	2,041	18	238	67	160	‡	114	72	156	197	40	82
1902	94,937	1,943	17	189	80	154	‡	73	82	172	219	34	77
1903	94,921	1,899	26	191	71	124	‡						
1904	94,905	1,738	18	177	73	126	‡						
1905	†94,889	1,899	17	178	70	148	‡						

* From Massachusetts State Registration Reports, except last four columns, which are from Reports of Lowell Board of Health. Stillbirths are excluded.

† Census years. U.S. Census on the even decades; State Census at the intermediate fifth year. Other populations interpolated by the "arithmetical" method.

‡ Title discontinued in State Reports. For certain of the less important causes only the period 1888–1902 inclusive has been included, the spaces for the remaining years being left blank.

From these figures the plots in Chart 5 have been constructed. These show the death-rates from various causes for a number of years, as for Lawrence, before and after the purification of the water-supply, including two U.S. Censuses and three state Censuses. Here, as at Lawrence, we have, therefore, a substantial basis for population statistics. The method of plotting is the same as for Hamburg and Lawrence. The gradual substitution of unpolluted for polluted water is represented by the tapering portion of the black bar. The

same scale is used for all curves except the bottommost, and here again the diagrams have been cut off so that no base-lines appear.

TABLE 10.

TOTAL DEATH-RATES, AND DEATH-RATES FROM CERTAIN DISEASES, LOWELL, MASS., 1883 TO 1905 INCLUSIVE, PER 100,000 OF POPULATION.*

Year	Total Death-Rate	Typhoid Fever	Pneumonia	Bronchitis	Pulmonary Tuberculosis	Cholera Infantum	Diphtheria and Croup	Apoplexy	Inanition, Marasmus, and Infantile Debility	Heart Disease	Old Age	Diseases of the Kidneys
Merrimac River, unpurified:												
1883	2,300	79	165	56	400	201						
1884	2,216	65	180	68	326	215						
1885	2,073	76	133	41	306	196						
1886	2,243	75	159	49	286	247						
1887	2,688	129	242	92	334	226						
1888	2,440	86	213	84	263	253	148	47	220	141	43	69
1889	2,530	92	193	97	284	287	135	52	212	188	73	61
1890	2,523	161	187	123	276	280	53	54	211	190	85	72
1891	2,499	99	237	121	281	318	20	56	196	197	77	84
1892	2,774	96	268	142	288	285	35	64	287	174	70	80
Years of change:												
1893	2,580	67	266	154	259	350	44	64	264	157	84	66
1894	2,156	61	165	108	226	266	43	45	176	148	61	57
1895	2,215	39	184	92	190	258	62	70	168	183	73	73
1896	2,222	44	182	99	214	256	53	59	172	177	79	74
Ground-water:												
1897	2,099	19	192	121	203	200	45	76	150	178	52	52
1898	1,994	28	182	110	207	204	41	68	127	180	54	100
1899	1,994	19	212	81	209	193	44	68	121	168	24	58
1900	1,948	20	219	91	191	139	28	81	144	200	42	77
1901	2,150	19	251	71	168	‡	120	76	164	207	42	86
1902	2,047	18	199	84	162	‡	77	86	181	231	36	81
1903	2,001	27†	201	75	131	‡						
1904	1,831	19	187	77	133	‡						
1905	2,001	18	188	74	156	‡						

* Computed from preceding table.

† Epidemic August, 1903, due to check-valve accident.

‡ Title discontinued in reports.

Changed from raw river water to deep wells. First ground-water pumped September, 1893. River water finally shut off February, 1896.

Beginning with the curve for typhoid fever, we find that here, as at Lawrence, the mortality had been subsiding, as was to be expected after the epidemic proportions of 1890; but sank still lower in the years of introduction of ground-water, remaining since at a comparatively low level.

Pneumonia, which had been on the whole rising, distinctly tho irregularly for many years, exhibits the striking phenomenon of an immediate drop from the high point which it had reached in 1893. The comparatively low level to which it now descended was, moreover,

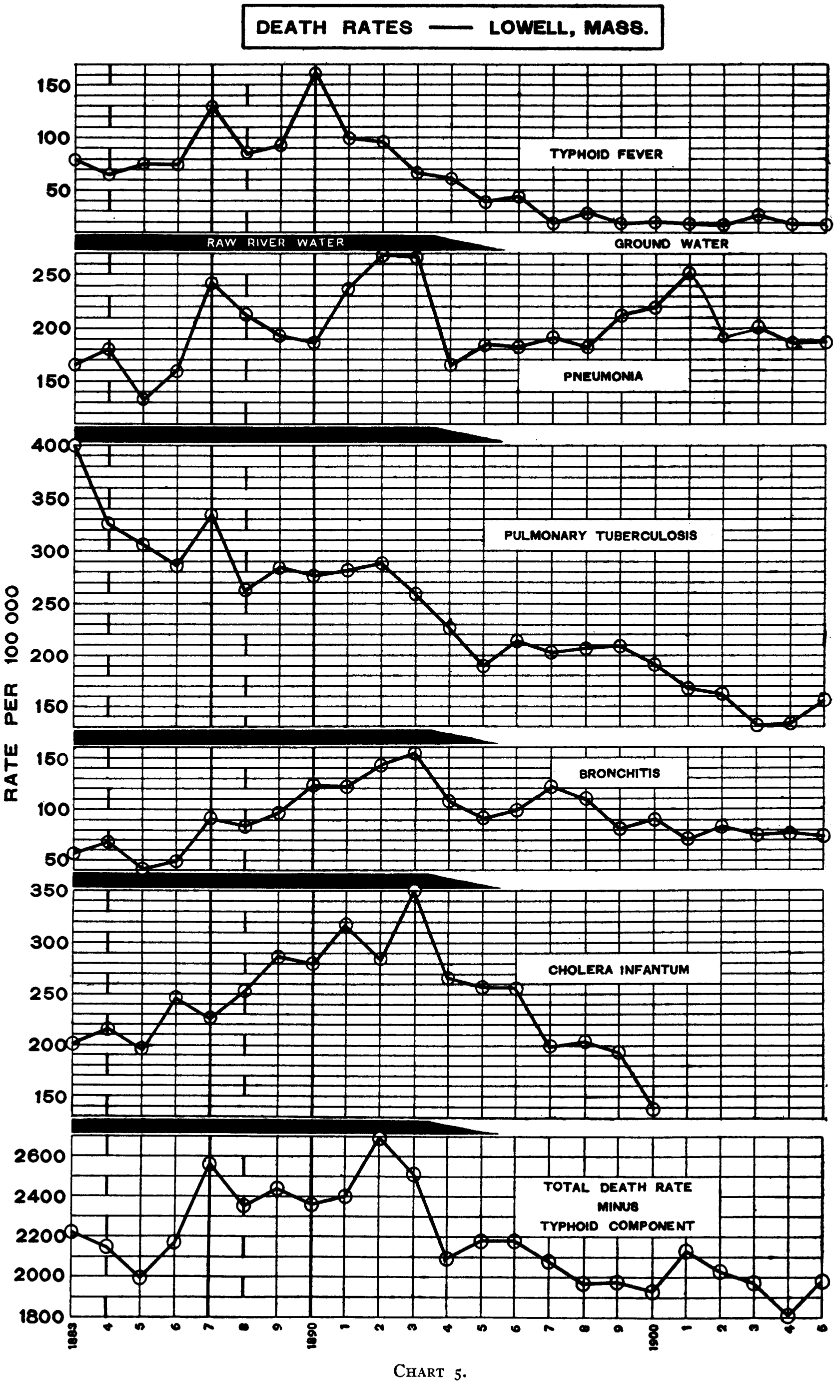
DEATH RATES —— LOWELL, MASS.
TYPHOID FEVER
RAW RIVER WATER
GROUND WATER
PNEUMONIA
PULMONARY TUBERCULOSIS
BRONCHITIS
CHOLERA INFANTUM
TOTAL DEATH RATE
MINUS
TYPHOID COMPONENT
RATE PER 100 000
150
100
50
250
200
150
400
350
300
250
200
150
150
100
50
350
300
250
200
150
2600
2400
2200
2000
1800
1883
4
5
6
7
8
9
1890
1
2
3
4
5
6
7
8
9
1900
1
2
3
4
5

CHART 5.

in general maintained, tho with certain fluctuations, up through the last year shown.

Pulmonary tuberculosis had been declining steadily prior to 1894, and from the curve no influence of purification of water-supply can be demonstrated, but that in this disease also the benefits of the better water were felt is clearly indicated by the analytical study in our contribution to the volume "Tuberculosis in Massachusetts" (referred to, p. 491 above) and by later study in sec. xvi of the present paper.

Bronchitis had been rising rapidly, up to the critical years 1894 and 1895, but at this time the whole trend of the curve was reversed, a distinct fall setting in—more rapid at first, and later settling gradually to the comparatively low level maintained for the last seven years of the period.

One of the most striking effects is seen in cholera infantum, which had been on the increase for some years before introduction of ground-water, but immediately afterward showed a rapid descent. Unfortunately reliable data for 1901 ff. were not available, but these years are less important than the years immediately following purification.

Finally, we discover, as at Lawrence, in the last curve of the chart an extraordinary demonstration of the Mills-Reincke phenomenon. The total death-rate minus typhoid component, which had risen as high as 27 and had scarcely gone below the excessive rate of 24 in the seven years prior to the critical years 1894–95, now shows in 1894 the surprising drop to a level of 21, sinking in subsequent years even lower.

XV. A GRAPHICAL DEMONSTRATION OF THE PHENOMENA AT MANCHESTER, NEW HAMPSHIRE, A CITY HAVING A WATER-SUPPLY OF GOOD QUALITY.

As a control or norm with which the phenomena at Lawrence and Lowell may be compared we have taken Manchester, N.H., a city which, as we have already stated, is in all important respects closely similar to Lawrence and Lowell. This similarity may be demonstrated statistically by reference to the U.S. Census for 1890 and 1900 and the Massachusetts State Census for 1895. We have taken from those sources figures relating to age, sex, and nativity distribu-

tion, and occupations of the population, which not only demonstrate the similarity of the three cities in the respects stated but also the fact that the three censuses show no significant differences in the percentages. It is a well-known fact that the mortality rates of communities may be considerably affected by the age distribution of the population, since death-rates are much higher for the very young and the very old. The death-rates of the age-groups under five years and over forty-five years are usually higher than that of the whole population, whereas the death-rates of other ages are lower, tho the limits may vary somewhat for different cities. By reference, for instance, to the Massachusetts State Registration Report for 1895, we ascertain the death-rate for that year for the whole population to be 19.01 per 1,000; the rate for the age-group under five years, 64; for the group five–ten, 6; for succeeding age-groups up to fifty, rates less than 19; but for all groups above fifty, rates higher again than that for the whole population. Again, as is well known, general death-rates are affected to greater or less extents by distribution according to sex, place of birth, and occupations of the population. We therefore present without further comment the following table:

TABLE 11.*

RATIOS OF:	PERCENTAGES							
	LAWRENCE			LOWELL			MANCHESTER	
	1890	1895	1900	1890	1895	1900	1890	1900
Age-groups under five and over forty-five to total population	28.0	28.2	28.6	27.4	27.9	28.4	27.2	29.1
Male population to total population	46.6	48.2	48.3	45.6	46.1	47.3	45.0	46.7
Persons born in Canada (English) to total population	10.0†	2.0	2.7	20.3†	1.9	4.7	28.1†	3.0
Persons born in Canada (French) to total population		8.9	11.2		15.2	15.4		23.6
Persons born in Great Britain‡ to total population	13.7	12.9	10.2	6.6	6.7	5.9	3.5	3.1
Persons born in Germany to total population	4.1	4.6	3.9	0.2	0.2	0.2	2.0	2.0
Persons born in Ireland to total population	17.2	14.4	11.3	16.3	14.9	12.8	9.8	7.4
Persons born in other countries to total population	0.9	3.8	6.4	1.1	5.3	4.1	2.1	3.5
Total foreign-born	45.9	46.6	45.7	44.5	44.2	43.1	45.5	42.6
Wage-earners to total population	34.9	....	35.7	35.7	....	33.0	34.8	33.4
Textile operatives¶ to total wage-earners	68.9	....	76.1	63.7	....	65.0	62.2	58.7

* Computed from U.S. Censuses, 1890 and 1900, and Massachusetts Census, 1895.

† Canada and Newfoundland.

‡ England, Scotland, and Wales.

¶ Workers in manufacture of cotton, woolen, knit, and worsted goods, and hosiery.

Thus the above statistics confirm and supplement the knowledge gained by the personal familiarity of the authors with these three cities that they are in all important respects closely similar.

The statistics upon which we have based our studies of Manchester are presented in Tables 12 and 13.

TABLE 12.

TOTAL DEATHS, DEATHS FROM CERTAIN DISEASES, AND POPULATION, MANCHESTER, N.H., 1883 TO 1905 INCLUSIVE.*

Year	Population	Total Deaths	Typhoid Fever	Pneumonia	Bronchitis	Pulmonary Tuberculosis	Cholera Infantum	Diphtheria and Croup	Apoplexy	Inanition, Marasmus, and Infantile Debility	Heart Disease†	Old Age	Nephritis, incl. Bright's Disease
Same water-supply, of good quality, throughout:													
1880	‡32,630												
1883¶	35,220	760	20	54	7	116	131						
1884	37,230	764	17	46	18	117	112						
1885	38,380	783	22	55	20	107	88						
1886	39,530	748	15	33	9	118	122						
1887	40,680	814	18	51	31	90	148						
1888	41,830	869	14	55	37	115	117	55	11	31	46	24	5
1889	42,980	778	18	53	35	78	86	49	18	22	47	18	12
1890	‡44,126	973	15	83	40	106	146	28	18	36	43	27	22
1891	45,410	895	19	85	38	98	122	9	15	24	42	18	17
1892	46,700	980	5	50	38	91	102	11	21	20	56	20	24
1893	47,980	1,013	14	66	43	91	86	7	23	21	44	28	13
1894	49,270	1,001	23	86	59	92	138	37	15	38	55	13	13
1895	50,560	1,036	21	107	55	83	144	26	19	47	80	22	16
1896	51,840	1,064	19	90	54	126	115	45	17	29	77	21	21
1897	53,130	1,140	12	119	88	111	123	38	29	39	70	18	22
1898	54,410	1,003	14	89	47	88	136	26	26	33	53	15	31
1899	55,700	1,061	11	134	65	101	92	13	31	61	69	21	31
1900	‡56,987	1,153	9	120	39	117	148	13	34	56	84	21	30
1901	58,270	1,143	9	115	37	104	132	8	27	35	88	13	36
1902	59,560	1,088	8	121	55	78	§	30	38	§	72	20	28
1903	60,850	1,112	9	112	41	79	§						
1904	62,130	1,015	12	101	31	87	§						
1905	63,420	1,339	11	129	22	108	§						

* From N.H. State Registration Reports, except last four columns, which were kindly furnished by Dr. Irving A. Watson, State Registrar of Vital Statistics, N.H. For certain of the less important causes only the period 1888–1902 inclusive has been included, the spaces for the remaining years being left blank. Stillbirths are excluded.

† Including angina pectoris, embolism, and phlebitis.

‡ U.S. Census years. Intermediate populations interpolated by the "arithmetical" method.

¶ Year ending March 31, 1883.

§ Change of classification.

From these death-rates we have constructed the diagrams in Chart 6, using the same method of plotting as for Hamburg, Lawrence, and Lowell. As Manchester had a water-supply of good quality throughout, there are no black bars.

Typhoid fever remained at a fairly low level throughout the period, and this was to be expected from the character of the water-supply. This curve therefore affords a valuable background for viewing the typhoid fever death-rates of the other two cities.

TABLE 13.

TOTAL DEATH-RATES, AND DEATH-RATES FROM CERTAIN DISEASES, MANCHESTER, N.H., 1883 TO 1905 INCLUSIVE, PER 100,000 OF POPULATION.*

Year	Total Death-Rate	Typhoid Fever	Pneumonia	Bronchitis	Pulmonary Tuberculosis	Cholera Infantum	Diphtheria and Croup	Apoplexy	Inanition, Marasmus, and Infantile Debility	Heart Disease†	Old Age	Nephritis, incl. Bright's Disease
1883	‡2,158	57	153	20	329	372						
1884	2,052	46	124	48	314	301						
1885	2,040	57	143	52	279	229						
1886	1,892	38	84	23	299	309						
1887	2,001	44	125	76	221	364						
1888	2,077	33	132	88	275	280	132	26	74	110	57	12
1889	1,810	42	123	81	181	200	114	42	51	109	42	28
1890	2,205	34	188	91	240	331	63	41	82	97	61	50
1891	1,971	42	187	84	216	269	20	33	53	93	40	37
1892	2,099	11	107	81	195	219	24	45	43	120	43	51
1893	2,111	29	138	90	190	179	15	48	44	92	58	27
1894	2,032	47	175	120	187	280	75	30	77	112	26	26
1895	2,049	42	212	109	164	285	51	38	93	158	44	32
1896	2,052	37	174	104	243	222	87	33	56	149	41	41
1897	2,146	23	224	166	209	232	72	55	73	132	34	41
1898	1,842	26	164	86	162	250	48	48	61	97	28	57
1899	1,905	20	240	117	181	165	23	56	109	124	38	56
1900	2,023	16	210	68	205	260	23	60	98	147	37	53
1901	1,962	15	197	64	179	227	14	46	60	151	22	62
1902	1,827	13	203	92	131	...	50	64	...	121	34	47
1903	1,827	15	184	67	130	...						
1904	1,634	19	163	50	140	...						
1905	2,111	17	204	35	170	...						

* Computed from preceding table.

† Including angina pectoris, embolism, and phlebitis.

‡ Year ending March 31, 1883.

Same surface water-supply, of good quality, throughout.

Pneumonia was rising steadily tho irregularly until 1899, and at the very time (1894) when Lawrence experienced an extraordinary drop in pneumonia and Lowell one nearly as great, the rate for Manchester had risen higher than it had ever been before in the period considered; and then while the rates at Lawrence and Lowell remained at the level to which they had fallen, that at Manchester, on the whole, rose.

For pulmonary tuberculosis the Manchester curve, like those for the other two cities, was throughout the period falling gradually,

but its rate of fall was in comparison not so rapid, the years 1896 and 1897 even showing a marked rise.

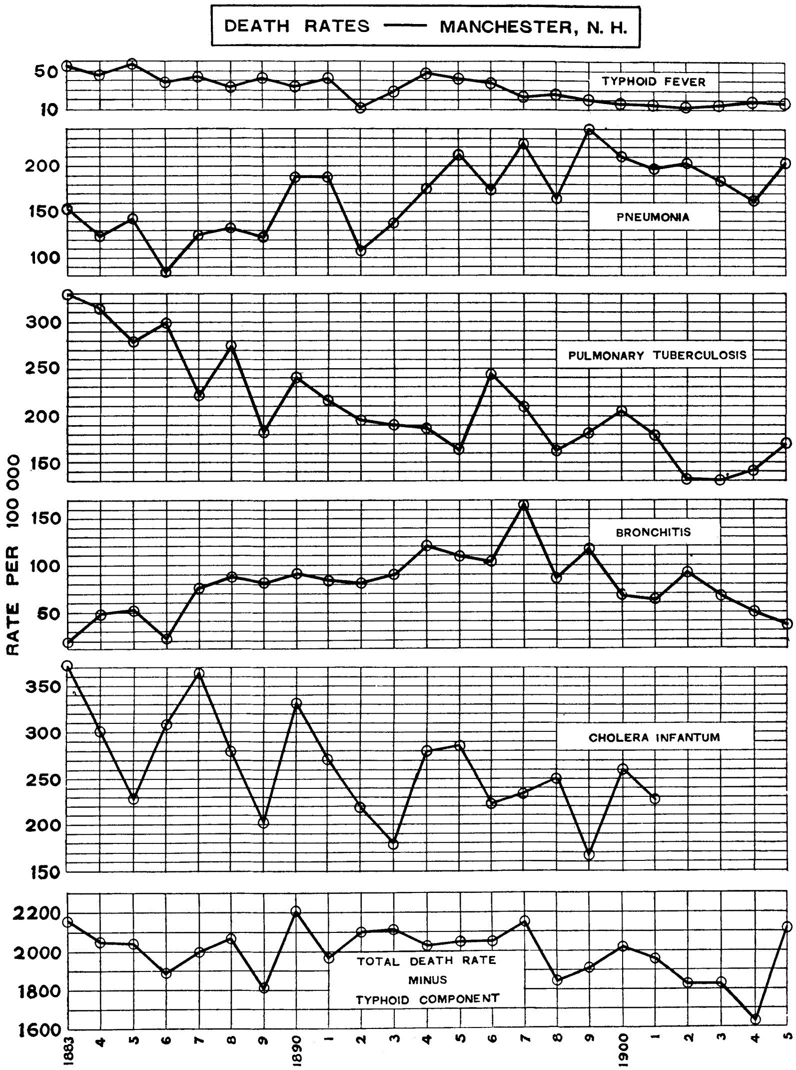

Chart 6.

Bronchitis, like pneumonia, was rising at Manchester until 1897, while at Lowell there was a decline in this disease following the introduction of ground-water. At Lawrence the decrease in bron-

chitis had already set in before filtration, hence without the further detailed studies which we present in sec. xvi, the fact that Lawrence experienced a greater decline than the norm cannot be readily seen.

In cholera infantum the curve for Manchester is highly irregular, but in the years 1894 and 1895, when that disease had dropped markedly in the other two cities, the rate for Manchester had risen to a maximum.

In the curve for total death-rate minus typhoid component Manchester shows a close adherence to a level of about 2,000 from 1892 to 1897, thus covering the period when Lawrence and Lowell changed their water-supplies and experienced remarkable drops in that death-rate, which had in these two cities been at a much higher level.

We shall not pause here any longer to discuss Lawrence and Lowell as compared with Manchester, reserving for sec. xvi the detailed study of the comparative relations among these three cities.

XVI. A COMPARATIVE STUDY OF THE DATA DERIVED FROM LAWRENCE, LOWELL, AND MANCHESTER.

We have seen in secs. xiii, xiv, and xv that both at Lawrence and at Lowell there followed immediately upon purification of the water-supply a lasting drop in the total death-rate—a drop much greater than could be accounted for by the decrease in typhoid fever alone; while the total death-rate at Manchester showed no such change, but kept steadily on the same comparatively low level.

The drops at Lawrence and Lowell we shall examine somewhat more closely in order to determine: (1) the extent of the reductions in their total death-rates in comparison with the norm, Manchester; and (2) what causes of death played the principal parts in these reductions. Throughout we shall compare Lawrence and Lowell with each other and with the norm, Manchester.

In the analysis of the declines we have first taken seven chief causes of death, omitting "accident," as given in the tables of the Massachusetts State Registration Report for 1890. These are: phthisis, causing in that year 5,791 deaths; pneumonia, 4,038; cholera infantum, 2,491; diphtheria and croup, 1,626; bronchitis, 1,533; apoplexy, 1,301; and typhoid fever, 835; making a total of 17,615 deaths. The total number of deaths in Massachusetts for

the year was 43,528. In addition to this list we have taken several important general headings given in most nosological arrangements, in order to include diseases of all the general classes, viz.: inanition, marasmus, and infantile debility; heart disease; old age; and diseases of the kidneys. The sum of all titles above mentioned formed 50 to 60 per cent of the total deaths in Manchester, Lowell, and Lawrence, and if causes of death other than disease be omitted, the percentage is somewhat higher.

It may be objected that a few of these titles, e.g., old age, are too vague to serve in an accurate analysis, and the objection is valid so far as exact and absolute determinations of mortality are concerned. For purposes of comparison of the rates in the same city at periods not much separated, however, the indefiniteness of any given title does not greatly affect its value in the analysis. The limits covered by any title depend upon the local usage of the medical profession in the community in question; and as such usage commonly changes only gradually, year to year comparisons are not seriously interfered with. The important phenomena considered in this paper are *sudden* decreases in death-rates taking place within a short space of time.

Mortality statistics for the various causes of death, illustrating the phenomena at Lawrence and Lowell, as compared with the norm, Manchester, before and after water-supply purification, are given in Tables 14 and 15. By the use of averages for periods of five years before and after, a safer if less striking view of the facts is obtained.

From the first of these tables have been plotted Charts 7 and 8, which largely explain themselves. It must be observed that the periods of five years each, before and after water-supply purification, do not quite correspond for Lawrence and Lowell, so that the corresponding Manchester blocks in the upper and lower halves of the chart do not represent exactly the same periods for that city.

These diagrams demonstrate certain points which do not clearly appear in the curves in Charts 4 and 5, one of the chief advantages being that the movements of the rates in Manchester, the norm, are readily seen in direct comparison with those in the other two cities. Thus, for example, the stationary bronchitis rate at Lawrence is seen to be actually a gain because that at Manchester increased; a point which does not appear in the Lawrence curve alone.

In order that the actual extent of the decreases in death-rates may be determined, reckoned against the corresponding changes at

TABLE 14.

MORTALITY RATES FROM CERTAIN DISEASES IN LAWRENCE, MASS. (AS COMPARED WITH MANCHESTER, N.H.), BEFORE AND AFTER WATER-SUPPLY PURIFICATION.

Mean annual death-rates (per 100,000) for five-year periods just before, and just after, introduction of filtration at Lawrence.

	Lawrence		Manchester	
	1888–1892 (Before)	1894–1898 (After)	1888–1892 (Same Periods as for Lawrence)	1894–1898
Typhoid fever	119	32	32	35
Pneumonia	255	202	148	190
Bronchitis	49	47	85	117
Pulmonary tuberculosis	244	185	222	192
Cholera infantum	222	201	260	254
Diphtheria and croup	152*	59	71	67
Apoplexy	55	62	37	41
Inanition, marasmus, and infantile debility	146	100	61	72
Heart disease	126	119	106	130
Old age	42	37	49	35
Diseases of the kidneys	36	36	36	39
Total death-rate	2,494	1,998	2,032	2,024

* Epidemic in 1889, when the rate rose to 391.

TABLE 15.

MORTALITY RATES FROM CERTAIN DISEASES IN LOWELL, MASS. (AS COMPARED WITH MANCHESTER, N.H.), BEFORE AND AFTER WATER-SUPPLY PURIFICATION.

Mean annual death-rates (per 100,000) for five-year periods just before, and just after, introduction of ground-water at Lowell.

	Lowell		Manchester	
	1889–1893 (Before)	1896–1900 (After)	1889–1893 (Same Periods as for Lowell)	1896–1900
Typhoid fever	103	26	32	24
Pneumonia	230	197	149	202
Bronchitis	127	100	85	108
Pulmonary tuberculosis	278	205	205	200
Cholera infantum	304	198	240	226
Diphtheria and croup	57	42	47	51
Apoplexy	58	70	42	50
Inanition, marasmus, and infantile debility	234	143	55	79
Heart disease	181	181	102	130
Old age	78	50	49	36
Diseases of the kidneys	73	72	39	50
Total death-rate	2,581	2,051	2,039	1,994

Manchester, as well as independently, we have also made the computations presented in Table 16.

From these figures it is seen that when the decreases in Manchester are taken into account, and subtracted algebraically with the proper

signs, as normal, from those in the other two cities, the declines in certain diseases in the latter cities stand out from the obscurity

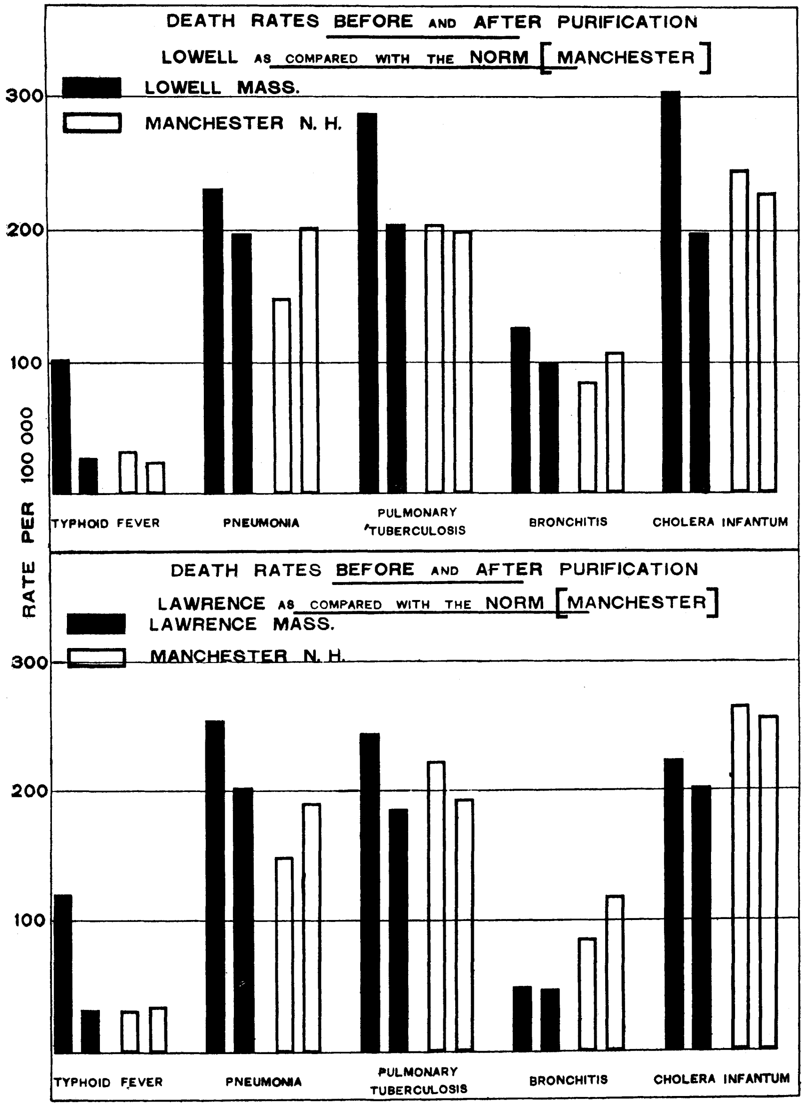

CHART 7.

in which they are masked when only the actual decreases are considered. Chief among these diseases are pneumonia and bronchitis.

Taking up first typhoid fever, and referring to Chart 7 as well as to the tables just given, we find that the rates at Manchester from that disease show the good and unvarying quality of the water-supply there, thus demonstrating the city's normality in that respect. The great drops at the other two cities following water-supply purification stand out clearly.

TABLE 16.

DECREASES IN DEATH-RATES FROM CERTAIN CAUSES IN LAWRENCE AND LOWELL FOLLOWING WATER-SUPPLY PURIFICATION.

Rates are per 100,000 population.

CAUSES OF DEATH	DECREASES IN DEATH-RATES							
	APPARENT (COMPUTED DIRECTLY)				TRUE (SUBTRACTING ALGEBRAIC DECREASE AT MANCHESTER AS NORMAL)			
	LAWRENCE		LOWELL		LAWRENCE		LOWELL	
	Decrease	Percentage of Total Decrease	Decrease	Percentage of Total Decrease	Decrease	Percentage of Total Decrease	Decrease	Percentage of Total Decrease
Typhoid fever	87	18	77	15	90	18.5	69	14
Pneumonia	53	11	33	6	95	19.5	86	18
Bronchitis	2	0	27	5	34	7	50	10
Pulmonary tuberculosis	59	12	73	14	30	6	68	14
Cholera infantum	21	4	106	20	15	3	92	19
Diphtheria and croup	93	19	15	3	89	18	19	4
Inanition, marasmus, and infantile debility	46	9	91	17	57	12	115	24
Old age	5	1	28	5	−9	−2	15	3
Other causes	130	26	80	15	87	18	−29	−6
All causes	496	100	530	100	488	100	485	100

In respect to pneumonia, while Manchester rose markedly from 148 to 190, Lawrence dropped from the high rate of 255 to the normal of 202. Lowell shows a similar decrease. In both cases the closeness of the rates, after improvement, to those of Manchester is additional evidence for the conclusion that the polluted water had caused an abnormally high rate, which declined at once, on the removal of the pollution, to the normal level.

Pulmonary tuberculosis was decreasing in Massachusetts and New Hampshire during the period 1890–1900. The diminution for the state of Massachusetts—shared fully, as detailed study shows, by cities of the same class as Lawrence and Lowell—is indicated by the following rates per 100,000 from the state registration: for 1890,

259; for 1895, 219; and for 1900, 185. Similarly in New Hampshire the rates were: for 1890, 219; for 1895, 177; and for 1900, 158. In a comparison of Manchester and Lawrence, both cities show a decrease, but that in Manchester is comparatively small. The decrease in the latter is what might be expected from general improvement in sanitary conditions. Lawrence starting higher came down to about the level of the norm. Lowell shows the same phenomenon as compared with Manchester, but in much more marked degree. In actual figures Lawrence shows a decrease 30 greater than the normal, and Lowell, 68 greater. These facts, in spite of many complicating factors, indicate a certain amount of decrease due to the change in water-supply. Phthisis being a disease of slow development and often long-postponed fatality, an effect on the mortality could hardly be expected to appear immediately after an improvement in one condition favoring its spread or fatality; and where many such conditions are involved the effect might well be somewhat obscured. We wish therefore to emphasize particularly the evidence here given that both at Lawrence and at Lowell there were decreases in pulmonary tuberculosis following water-supply purification considerably greater than the corresponding normal decreases at Manchester, as this point is not distinctly demonstrable by the curves for the former cities alone.

Bronchitis, which includes both chronic and acute disease, shows much the same phenomena as does pneumonia. At Manchester the rate rose distinctly; at Lawrence, however, it did not rise, but remained stationary; while at Lowell there was actually a decrease amounting to 50 more than the normal decrease. This also is a case of improvement which is much better demonstrated by the blocks of Chart 7 than by the curves.

Cholera infantum, a general title indicative of intestinal diseases of infants, shows a decrease in all three cities. In Lawrence, however, there was a decrease of 15 more than the normal, while Lowell shows a remarkable corresponding surplus decrease of 92. The latter stands out as one of the most striking phenomena observed, and recalls with emphasis Dr. Reincke's statement that the mixing of raw river water with milk caused much of the infant mortality at Hamburg (pp. 497, 500, 502, above). The same

explanation probably also holds good to a very great extent for Lawrence and Lowell.

Among the minor causes of death not plotted in the charts, tho included in the tables, we consider first inanition, marasmus, and infantile debility, a heterogeneous and indefinite title, but one fairly indicative of the mortality of the feeble. Infantile debility makes up a large part of it, and probably a considerable number of deaths from diarrhea and the gastro-intestinal diseases of infants are here included through false diagnosis. As seen from the tables, both at Lawrence and at Lowell the mortality shows a great decrease, while at Manchester a considerable rise took place. On account of the tendency in diagnosis just mentioned it well may be that much of the effect of water-supply purification at Lawrence upon infant mortality is indicated by this title, the cholera infantum rate not having been much lowered.

For old age the figures indicate a slight rise at Lawrence, but at Lowell a decrease distinctly greater than the normal.

Heart disease (uncertain in diagnosis) shows improvements greater than the normal by about 30.

In diseases of the kidneys and apoplexy there are no phenomena worthy of mention.

With reference to diphtheria and croup the mixt character of the title, the highly epidemic character of diphtheria, and the use of antitoxin complicate matters so much that we can draw no conclusions from the figures.

The Mills-Reincke phenomenon at both Lawrence and Lowell is shown very strikingly by Chart 8. (We must caution the reader, that in order to save space the blocks in this chart have been cut off so that their true bases do not appear.) Here the drops seen in the curves in Charts 4 and 5 are reduced to actual quantitative statement for five-year periods just before and after water-supply purification. At Lawrence the total death-rate minus typhoid component dropped from 23.7 to 19.7 per 1,000 with an annual saving of about 200 lives from causes other than typhoid fever. At Lowell it dropped from 24.8 to 20.3, with a saving of 365 lives from such causes. Manchester, on the other hand, shows decreases for the corresponding periods of only 0.1 and 0.4 respectively. In other words, the

REDUCTION IN DEATH RATE
FROM
DISEASES OTHER THAN TYPHOID FEVER
FOLLOWING
WATER SUPPLY PURIFICATION

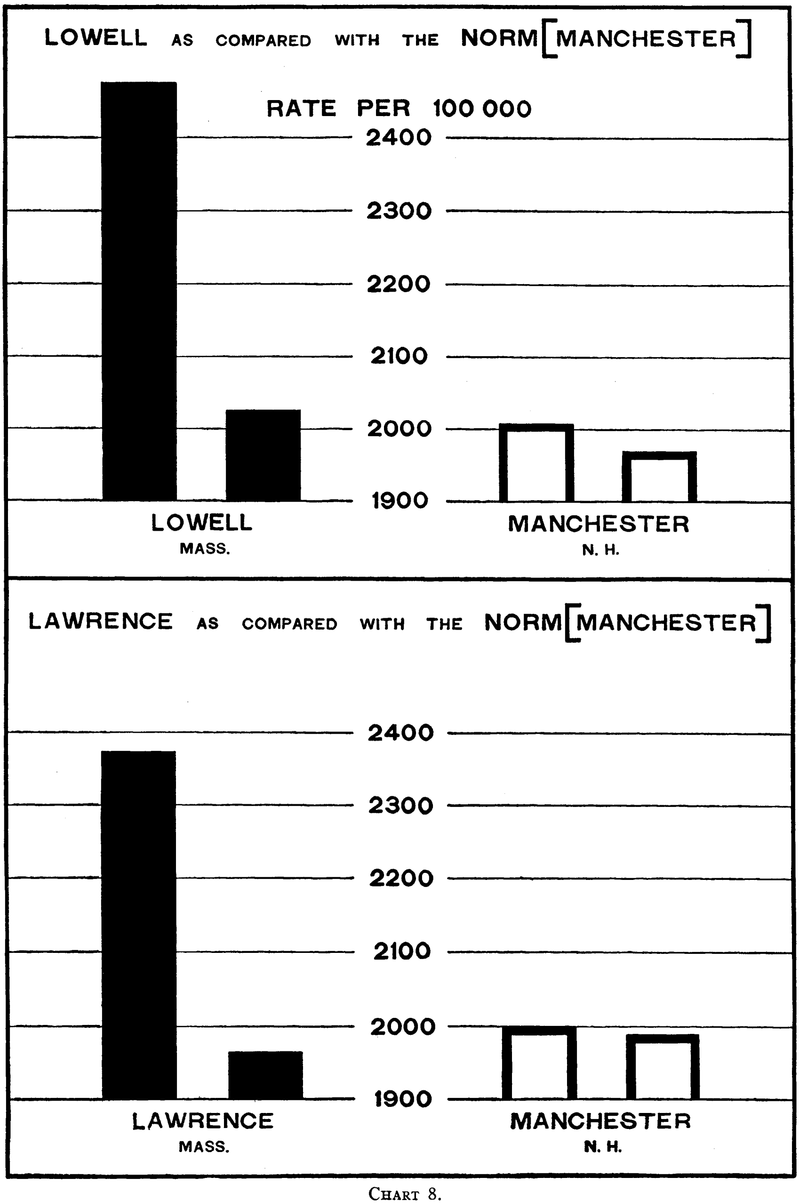

CHART 8.

first two cities, which had used polluted and unpurified water-supplies and had had very excessive "total minus typhoid" death-rates, dropped after purification to the normal and comparatively low rate level (*ca.* 20.0) which Manchester had maintained throughout.

The second of the two questions proposed at the outset of this section, i.e., what causes of death played the principal parts in the reductions in the total death-rates, is also answered in Table 16 above, by the percentage columns. If the rates for Lawrence and Lowell be averaged, over 80 per cent of the decreases in total death-rates—whether actual or comparative (against Manchester) rates be considered—are accounted for. In this decrease, the chief parts were played (besides typhoid fever) by pneumonia, pulmonary tuberculosis, cholera infantum, and inanition, marasmus, and infantile debility. Cholera infantum and the last three causes of death are, as we have already stated, somewhat related by diagnosis. And these results agree with those already obtained for Hamburg (secs. iv and v).

The foregoing analysis affords a basis for a testing of Hazen's theorem. As a preliminary computation we find that at Lawrence, for every death less from typhoid fever there were 4.7 deaths fewer from other causes, and at Lowell 5.9 fewer. These, however, are only crude ratios which include any rises or falls of the rates which would have taken place in any event independent of water-supply purification. It is therefore necessary, in order to obtain ratios comparable with that suggested by Mr. Hazen (which was based upon computations from which decreases due to causes other than water-supply purification had been approximately eliminated), to consider the decreases *minus* those at Manchester as normal. We compute, therefore, from Table 16, that—

> Where one death from typhoid fever has been avoided by the use of better water, a certain number of deaths [*4.4 at Lawrence and 6.0 at Lowell*] from other causes have been avoided.

Thus Mr. Hazen's estimate of two or three is seen to have been for these cities very conservative.

At this point we may briefly consider certain objections which may perhaps be raised against the accuracy of the foregoing statistical studies or our interpretation of them. We have already shown (sec.

iv) that for three census years (1890, 1895, and 1900) the age and sex distributions, the proportions of foreign-born of various nationalities, and the occupations of the population at Lawrence and Lowell were practically the same. Between census years there were undoubtedly fluctuations in these conditions, but any such could have been only temporary, as otherwise they would be indicated by the census figures. Of fluctuations in the actual number of the total population as related to population estimates we have made a special study, the results of which are submitted in sec. xviii. Anticipating, we may state here our conclusion that no error seriously affecting our results has been introduced from that direction. Moreover, important fluctuations in quality or quantity of population at Lawrence and Lowell should have had a counterpart at Manchester, a city in all essential respects similar, with which comparisons have throughout been made. The same remark applies also to mortality decreases due to general sanitary and medical improvement (upon which, it will be remembered, Dr. Reincke laid considerable stress in the case of Hamburg).

Such *sudden* and *lasting* decreases in death-rates as took place in each of these cities can be explained only by sudden and permanent measures of sanitation, and it is impossible to escape the conclusion that the principal part in the drop in total death-rate—the Mills-Reincke phenomenon—both at Lawrence and at Lowell, was played by the purification of the public water-supply.

XVII. STUDIES OF SIMILAR PHENOMENA IN SOME OTHER AMERICAN CITIES

1. *Albany, N.Y.* — As another example of the Mills-Reincke phenomenon occurring in a prominent city which has purified its public water-supply and for which reliable vital statistics are obtainable, we present Albany, N.Y.

Previous to 1899 two-thirds of the total water-supply of this city was taken from the Hudson River without purification, while the remaining third came by gravity from watersheds just west of the city. In September, 1899, slow sand filtration of the Hudson River supply was introduced, while the surface water-supply remained unchanged. The statistics upon which we have based our demonstration of the Albany phenomena are given in the following Tables 17 and 18.

The death-rates for Albany are plotted on Chart 9, in which the same methods of presentation are employed as for Hamburg, Lawrence, and Lowell.

TABLE 17.

TOTAL DEATHS, DEATHS FROM CERTAIN DISEASES, AND POPULATION, ALBANY, N.Y., 1885–1907 INCLUSIVE.*

Year	Population	Total Deaths	Typhoid Fever	Acute Respiratory Diseases	Pulmonary Tuberculosis	Diarrheal Diseases	Deaths under Five Years of Age
Before filtration:							
1880	†90,758						
1885	92.841	1,993	49	182	299	101	685
1886	93,257	‡2,005	‡79	‡255	‡302	‡117	‡667
1887	93,674	2,020	71	203	337	121	561
1888	94,090	2,332	74	283	312	137	773
1889	94,507	2,262	77	297	294	81	741
1890	†94,923	2,265	62	386	327	124	641
1891	94,846	2,383	108	421	310	150	632
1892	94,769	2,558	50	448	298	165	863
1893	94,692	2,140	58	381	257	103	578
1894	94,615	2,162	52	326	301	118	656
1895	94,538	2,345	162	311	287	147	697
1896	94,461	2,099	97	244	298	126	556
1897	94,384	2,013	84	312	259	107	490
1808	94,307	1,904	94	225	238	88	464
1899	94,230	1,991	82	263	248	72	510
After filtration:							
1900	†94,151	1,742	38	256	231	70	382
1901	94,996	1,751	20	220	239	42	298
1902	95,841	1,623	29	227	215	37	251
1903	96,686	1,808	19	242	228	39	321
1904	97,531	1,848	18	258	216	§	281
1905	¶98,374	1,813	19	227	212	§	329
1906	99,219	1,770	20	§	193	§	322
1907	100,064	1,900	20	§	177	§	313

* From Reports of the N.Y. State Dept. of Health.

† U.S. Census. ¶ State Census. Other populations interpolated by the "arithmetical" method.

‡ Eleven months only, December not being given.

§ Title discontinued in reports.

Typhoid fever, which had been excessively prevalent, dropped immediately after the introduction of filtration to a much lower level. In addition to this there took place a decrease in the total death-rate minus the typhoid component, Albany thus furnishing another illustration of the Mills-Reincke phenomenon. This fact was noticed and reported by Mr. Mills and others, before our work began.

The decreases in the mortality from certain diseases at Albany are somewhat different in degree from those observed at Lawrence, Lowell, and Hamburg. Altho the death-rates at Albany from acute respiratory diseases, pulmonary tuberculosis, and "diarrheal diseases" (not including typhoid fever) were lower after the introduction of filtration than before, it must be noted that all three rates had been declining

before that time, and that in none of them does there appear any greater rapidity of decline setting in at this time. The most noticeable result shown by any curve of chart (except that for typhoid fever) appears in the death-rate under five years of age, for which the rate of decline just subsequent to 1899 was somewhat greater than it had been before. Falling to about 300, it continued

TABLE 18.

TOTAL DEATH-RATES, AND DEATH-RATES FROM CERTAIN DISEASES, ALBANY, N.Y., 1885 TO 1907 INCLUSIVE, PER 100,000 OF POPULATION.*

Year	Total Death-Rate	Typhoid Fever	Acute Respiratory Diseases	Pulmonary Tuberculosis	Diarrheal Diseases	Deaths under Five Years of Age
Before filtration:						
1885	2,147	53	196	322	109	738
1886	†2,150	†85	†274	†324	†126	†716
1887	2,157	76	217	360	129	599
1888	2,478	79	301	332	146	821
1889	2,393	81	314	312	86	784
1890	2,386	65	407	345	131	675
1891	2,512	114	444	327	158	667
1892	2,699	53	472	315	174	911
1893	2,260	61	402	271	109	610
1894	2,285	55	345	318	125	694
1895	2,480	171	329	304	156	738
1896	2,222	103	259	316	134	589
1897	2,133	89	331	274	114	519
1898	2,019	100	239	252	93	492
1899	2,113	87	279	263	76	542
After filtration:						
1900	1,850	40	272	246	74	406
1901	1,843	21	232	252	44	314
1902	1,693	30	237	224	39	262
1903	1,870	20	250	236	40	332
1904	1,895	18	265	222	‡	288
1905	1,843	19	231	216	‡	334
1906	1,783	20	‡	194	‡	325
1907	1,899	20	‡	177	‡	313

* Computed from preceding table. Slow sand filter since September, 1899, for Hudson River water, which furnishes about two-thirds of total supply. One-third of supply, both previous and subsequent to introduction of filtration, has been composed of impounded surface water.

† Eleven months only.

‡ Title discontinued in reports.

at that level up through the last year we have taken, 1907. This phenomenon is not, however, clearly reflected in the curve for total death-rate minus typhoid component, which shows no greater rapidity of decline after introduction of filtration. But even the fact that the decline in total death-rate continued as rapid as before may be in part due to the improvement of the water-supply, for it might perhaps otherwise have risen. The effect, nevertheless, is not nearly so clear-cut as in the cases of Hamburg, Lawrence, and Lowell, and requires explanation. Such explanation we believe

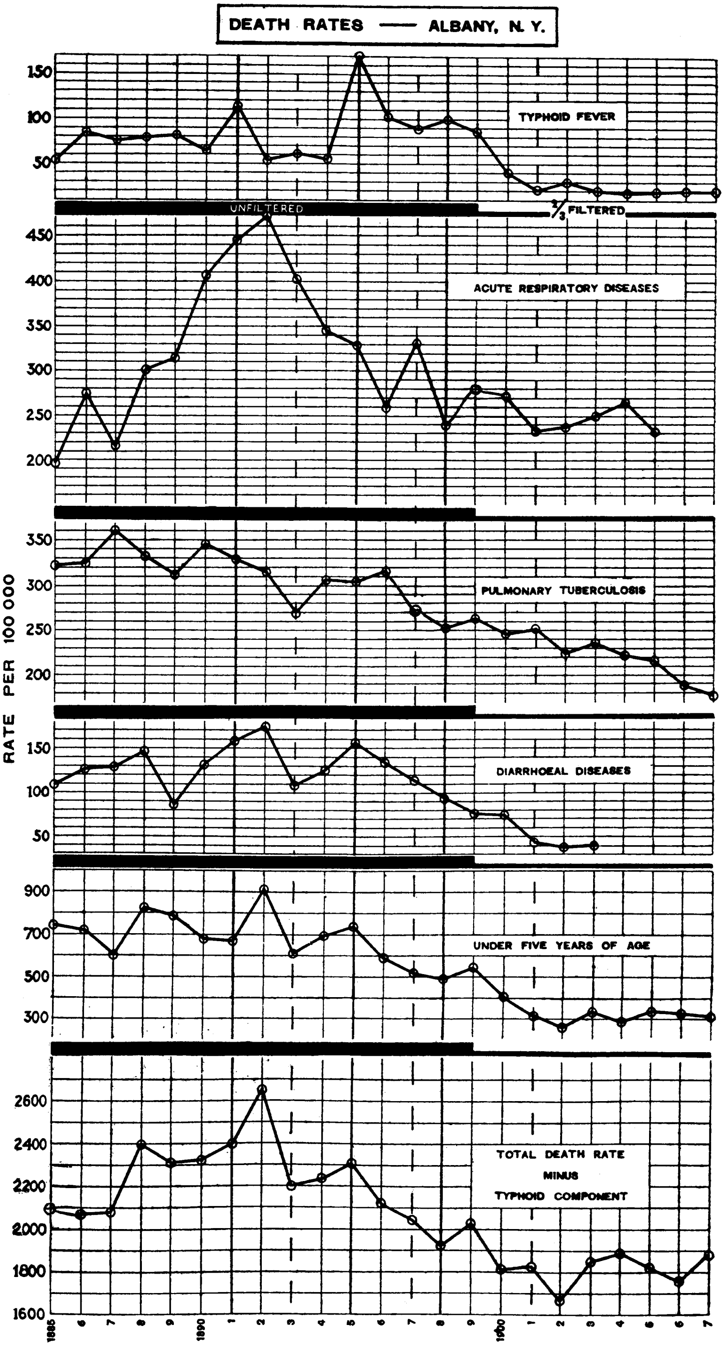
DEATH RATES —— ALBANY, N. Y.
TYPHOID FEVER
UNFILTERED
2/3 FILTERED
ACUTE RESPIRATORY DISEASES
PULMONARY TUBERCULOSIS
DIARRHOEAL DISEASES
UNDER FIVE YEARS OF AGE
TOTAL DEATH RATE MINUS TYPHOID COMPONENT
RATE PER 100 000
1885
1890
1900

Chart 9.

may possibly be found in the fact that one-third of the water-supply has come, and still comes, without purification, from the surface sources mentioned, the quality of which is said to be somewhat uncertain. It is possible at any rate that if the whole of a supply be not purified, the resultant drop in total death-rate minus typhoid component may be much less, even tho there be, as in this case, a decided diminution in typhoid fever. We greatly regret that we have had no such personal familiarity with conditions at Albany as we have enjoyed with the various cities on the Merrimac River, and that we must leave to others possessing fuller acquaintance with local conditions the task of clearing up local difficulties.

From average death-rates for periods of five years before and after the introduction of filtration (omitting the year 1899 itself), we compute that for every death less from typhoid fever after that date, there were still, even here, 4.1 fewer from other causes. This ratio is of course uncorrected for diminutions in mortality due to other factors than filtration, so that, tho affording an approximate indication, it cannot strictly be substituted in Hazen's theorem.

2. *Binghamton, N.Y.* — Among other examples of the Mills-Reincke phenomenon which have come to our attention, we may include Binghamton, N.Y., altho this city exhibits great irregularities which distinguish it from the examples we have already discussed. Binghamton took its water-supply without purification from the Susquehanna River until June, 1902, when mechanical filtration was introduced. Certain vital statistics for this city are given in Table 19.

From these figures our Chart 10 has been constructed. It will be observed that, following the introduction of filtration, the typhoid fever death-rate, which had been excessive, tho irregular, fell to a low level and remained there. The total death-rate minus typhoid component reflected this fall, altho one year, 1904, shows a rate higher, with the exception of only two previous years, than any rate since at least 1885. This irregularity shows that this is not altogether a clear case of the Mills-Reincke phenomenon, and therefore requires for a complete solution further elucidation.

Altho the authors have been unable to give to the case any local study such as it imperatively demands, certain facts deserve

mention. In the first place, both curves had before filtration shown very great irregularities, that for total death-rates minus typhoid component in particular having at one time fluctuated from 13 to 20 inside of four years. Typhoid fever had in certain years receded to a comparatively low rate, and the same is true of the total death-rate. When we consider, also, the small numbers with which we have to deal and the consequent unsteadiness of the statistics, it becomes evident that, in the absence of more detailed and thorough local studies, too much reliance should not be placed upon them.

TABLE 19.

VITAL STATISTICS OF BINGHAMTON, N.Y.*

YEAR	POPULATION	TYPHOID FEVER		TOTAL DEATHS	TOTAL DEATH-RATE PER 1,000
		Deaths	Death-Rates per 100,000		
Before filtration:					
1880	†17,317				
1886	27,929	3	11	333	11.9
1887	29,698	14	47	433	14.6
1888	31,467	32	102	493	15.7
1889	33,236	34	102	465	14.0
1890	†35,005	21	60	545	15.6
1891	35,469	32	90	668	18.8
1892	35,933	18	50	667	18.6
1893	36,397	16	44	622	17.1
1894	36,861	18	49	584	15.8
1895	37,325	13	35	540	14.5
1896	37,789	9	24	494	13.1
1897	38,253	13	34	498	13.0
1898	38,717	28	72	584	15.1
1899	39,181	10	26	681	17.4
1900	†39,647	17	43	822	20.7
1901	40,125	21	52	755	18.8
1902	40,603	11	27	725	17.9
After:					
1903	41,081	4	10	619	15.1
1904	41,559	4	10	762	18.3
1905	‡42,036	5	12	678	16.1
1906	42,514	5	12	678	15.9
1907	42,992	8	19	673	15.6

* Compiled and computed from Reports of N.Y. State Dept. of Health.

† U.S. Census ‡ State Census. Other population figures interpolated by the "arithmetical" method. Mechanical filter since June, 1902.

On going through the Annual Reports of the New York State Board of Health in an endeavor to discover, if possible, the specific reason or reasons for the peak in total death-rate minus typhoid component in 1904, we have found that there did indeed occur in that year in Binghamton epidemics of measles and diphtheria and an unusual number of deaths from phthisis. These, however, explain only one-third of the excess of the rate for this year over the average rate

for the following three years. In short, we have been unable to arrive at a satisfactory explanation of the irregularity of the total death-rate curve since 1902. We have nevertheless included Binghamton in

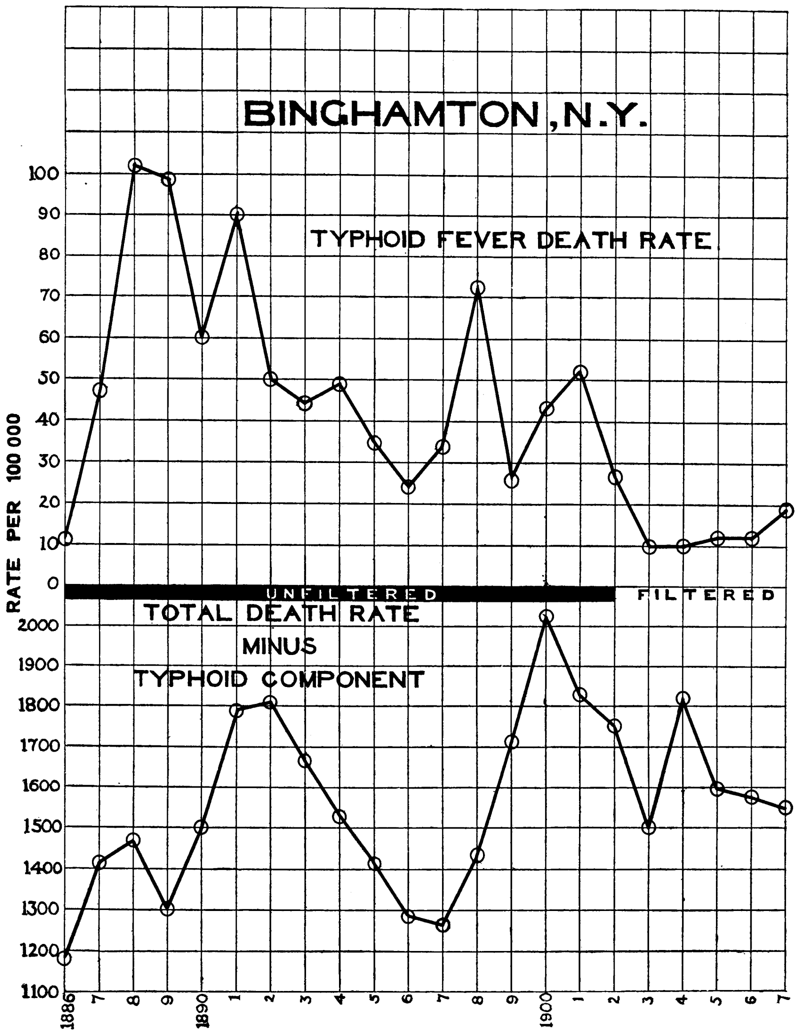

CHART 10.

our studies as an example, tho not a very clear one, of the Mills-Reincke phenomenon.

Taking periods of five years before and after filtration, we compute

that for one death less from typhoid fever afterward there were 1.5 fewer from other causes—this being merely an uncorrected ratio not applicable directly as a test of Hazen's theorem.

3. *Watertown, N.Y.*—As a city which had suffered severely from typhoid fever and which, after a noted epidemic in 1904, had installed a mechanical filter plant, we were led to study *in absentia* Watertown, N.Y. In the foregoing section we have presented an atypical instance of the Mills-Reincke phenomenon, and we now submit a demonstration of a city where that phenomenon did not apparently occur at all after the filtration of the public water-supply.

Until 1904 Watertown took its water from the Black River, a stream polluted by the populations of a number of towns above. In September, 1904, mechanical filtration was introduced immediately following the famous typhoid fever epidemic studied and reported upon by Dr. George A. Soper. A comprehensive description of the city and its past and present water-supply is given in Dr. Soper's paper "The Management of the Typhoid Fever Epidemic at Watertown, N.Y., in 1904."[1]

We present herewith certain vital statistics for this city:

TABLE 20.
VITAL STATISTICS OF WATERTOWN, N.Y.*

YEAR	POPULATION	TYPHOID FEVER		TOTAL DEATHS	TOTAL DEATH-RATE PER 1,000
		Deaths	Death-Rates per 100,000		
Before filtration:					
1880	†10,697				
1888	13,919	7	50	294	21.1
1889	14,322	4	28	224	15.6
1890	14,725	6	41	234	15.9
1891	15,422	6	39	285	18.5
1892	16,119	8	50	371	23.0
1893	16,816	9	54	336	20.0
1894	17,513	15	86	312	17.8
1895	18,210	31	170	331	18.2
1896	18,907	9	48	312	16.5
1897	19,604	12	61	340	17.3
1898	20,301	19	94	291	14.3
1899	20,998	18	86	351	16.7
1900	†21,696	22	101	397	18.3
1901	22,446	8	36	347	15.4
1902	23,196	15	65	317	13.7
1903	23,946	17	71	356	14.9
1904	24,696	52	211	413	16.7
After:					
1905	‡25,447	6	24	384	15.1
1906	26,197	13	50	461	17.6
1907	26,947	10	37	504	18.7

* Compiled and computed from Reports of N.Y. State Dept. of Health.
† U.S. Census. ‡ State Census. Other population figures interpolated by the "arithmetical" method. Mechanical filter since September, 1904.

[1] *Jour. N.E. Water Works Assn.*, 22, p. 87.

For Watertown as for Binghamton we have plotted the general death-rate and that from typhoid fever (Chart 11). The irregularities in both curves are even more evident than in the case of Binghamton. Typhoid fever was apparently not reduced by the introduction of filtration to as low and as permanent a level as should have been expected, for in 1906 we find that the rate had again risen to 50. The total death-rate minus typhoid component, instead of showing a decrease in 1905, 1906, and 1907, actually shows a rapid rise. Here, then, we find apparently the direct reverse of the Mills-Reincke phenomenon, and this fact requires explanation. The authors have been unable to undertake any complete and personal investigation of the local conditions, but may venture to point out briefly several factors possibly of importance.

As in the case of Binghamton, we must regard as suspicious the great irregularities of the curves. Even at certain times of high epidemic prevalence of typhoid fever—notably in 1904, and also in 1895 and 1898—the total death-rate remained at a comparatively low level; while the highest total death-rate shown on the diagram occurred in a year (1892) when typhoid fever, tho excessive, and not reached nearly the proportions of later years. These fluctuations are undoubtedly due in part to the small numbers dealt with, for in a population of only 21,696 (for 1900) the small number of deaths each year leaves much room for serious percentage fluctuations. This circumstance, however, can hardly furnish more than the beginning of an explanation.

A much more important fact in connection with the non-appearance of the Mills-Reincke phenomenon is that the typhoid fever death-rate itself was not reduced after filtration to nearly as low a level as would have been expected. Even after nearly two years from the beginning of filtration, we find a rate of 50 (in 1906), while for 1907 and 1908 (figures for the latter year just published) the rates were 37 and 40 respectively. These rates throw a strong suspicion on the efficiency of purification, and if a considerable amount of infection still remains in the filtered water, the Mills-Reincke phenomenon ought not to have been expected to appear. This point we wish to emphasize particularly, for, if the excess of typhoid fever in Watertown in 1906–8 was due to the water, that fact would

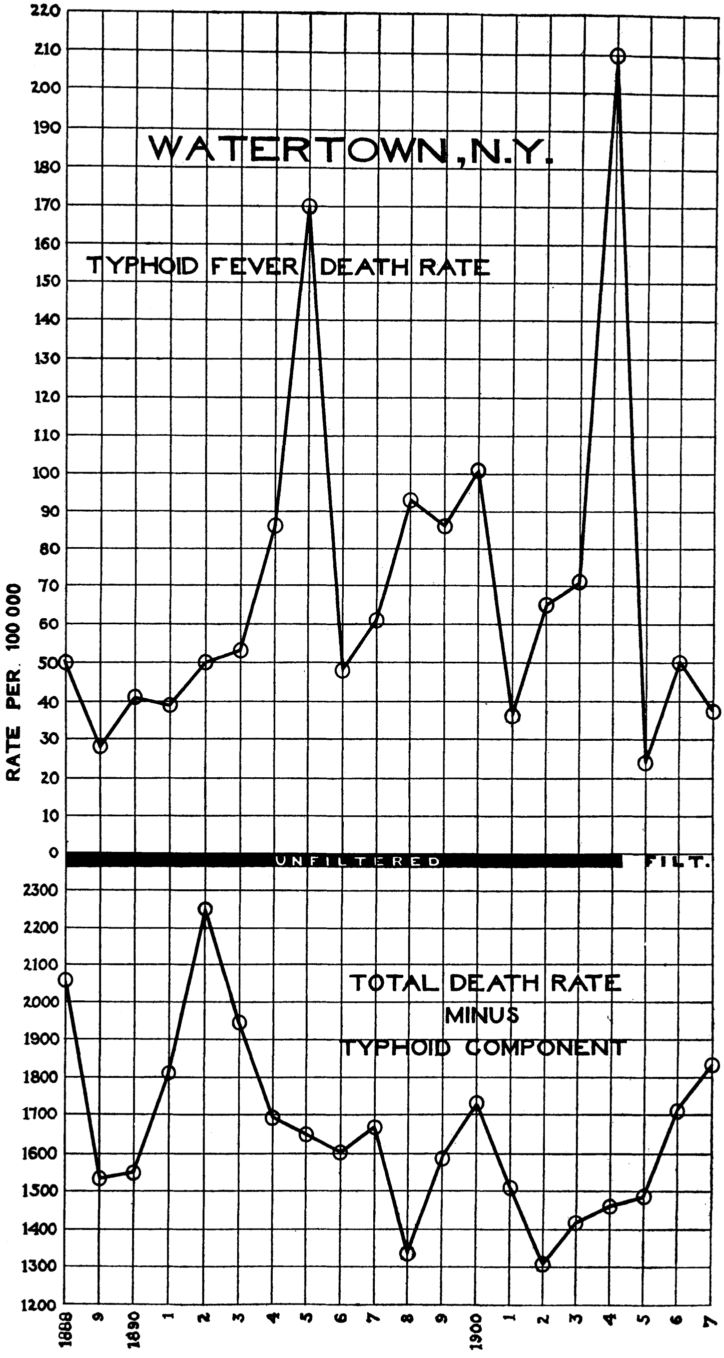
WATERTOWN, N.Y.
TYPHOID FEVER DEATH RATE
TOTAL DEATH RATE MINUS TYPHOID COMPONENT
RATE PER 100 000
UNFILTERED
FILT.
1888
1890
1900

CHART II.

afford sufficient reason for the absence of the Mills-Reincke phenomenon.

We understand that acids or other chemical substances in the waters of the Black River have at times, especially of low water, been present in sufficient concentration to interfere with the proper operation of the city filters. Evidence of such chemical pollution is not far to seek.

It is from the pulp and paper industries which have become well established on the river that the present gross pollution of the river is due. A number of mills are situated on the watershed with an aggregate output of over 300 tons of paper per day, in the manufacture of which sulphite pulp is used. Watertown is an active manufacturing city, and the river shows unmistakable signs of a high degree of pollution. All kinds of refuse are thrown directly into the stream, the paper mills and other factories using water in abundance to carry out factory wastes (Monthly Bulletin, N.Y. State Board of Health, July, 1908, p. 190).

The effect of the chemical waste is quite apparent in times of low water in the river. A change of color of 25 parts per million (platinum scale) in four hours is not unknown here. . . . . This color change is frequently accompanied by a decrease in the alkalinity of the raw water (F. H. Jennings in discussion of above-mentioned paper by Dr. Soper, p. 137).

It may be objected that if there were sufficient concentrations of chemical wastes in the river to interfere with the operation of the filters, most or all of the bacteria in the water would be killed by their disinfecting properties, for there is no doubt that such wastes as those from pulp mills have a marked germicidal effect.[1]

But it is probable that the composition of the water fluctuates widely and rapidly, as is asserted in one of the above quotations, and it is quite conceivable that water of high disinfecting powers with low bacterial content today might incapacitate the filters for dealing with water of low disinfecting power and high bacterial content tomorrow.

XVIII. FLUCTUATIONS OF POPULATION IN PERIODS OF PANIC AND PROSPERITY AS SOURCES OF STATISTICAL ERROR.

Very early in our studies we were struck with the fact that the beginnings of filtration in Lawrence and of substitution of groundwater at Lowell coincided almost exactly with the panic of 1893,

[1] See M. O. Leighton, "Prelim. Report on the Pollution of Lake Champlain," *Water Supply Paper No. 121, U.S. Geol. Survey, 1905*, Report of E. B. Phelps, p. 111. Also E. B. Phelps, "Pollution of Streams by Sulphite Pulp Waste," Paper No. 226 of *ibid.*, p. 7. Cf. *Penn. Health Bull.*, November 1909, on "The Germicidal Effect of Water from Coal Mines and Tannery Wheels upon Bacillus Typhosus, Bacillus coli, and Bacillus anthracis."

and the question naturally arose as to whether the diminished death-rates observed might not have been due, wholly or in part, to the influence of the panic. Our attention was first drawn to this important matter by newspaper references touching the effect of hard times upon health, particularly by an editorial in the Springfield (Mass.) "Republican" of June 30, 1908, from which it appeared that hard times are accompanied by a marked improvement in the public health. Corollaries were drawn to the effect that such improvement was doubtless due to less overworking, less overeating, less overdrinking, and the like—in short, to saner and more wholesome methods of living. And, certainly, following the period of financial depression in the United States setting in late in 1907, unusually low death-rates have been reported from many American cities. An article which has come to our notice, "Era of Low Mortality Reached by the Civilized World,"[1] states, for example, that for 1908 the death-rate for the registration states was, according to the U.S. Census, only 15.3 per 1,000 of population, this being, according to Dr. C. L. Wilbur of the Census, "probably the lowest death-rate that has ever occurred in the United States."

Our attention was independently drawn to the possibility of such an explanation as above mentioned of the lower death-rates at Lawrence by an employee connected with the registration of vital statistics in that city, who stated that to his personal knowledge there had taken place there, at the time of the panic of 1893, a marked change in the habits of the people, who began to spend more time in the open air, to make excursions into the country, and in general to live in a more leisurely and healthful manner. The new mode of life thus imposed upon the people was, it was argued, continued by force of habit even after the mills had again resumed full operation, more vacation time being then demanded by the employees. In the same discussion it was asserted also that there was a considerable change in the character of immigration at this time. It is, in fact, common knowledge among persons familiar with conditions in industrial cities that such phenomena do take place to a greater or less extent in hard times, with reverse effects in times of prosperity; and lower death-rates certainly have appeared in some cities at times of industrial depression.

[1] *Boston Med. and Surg. Jour.*, November 4, 1909.

On the other hand, there is good reason for believing that the simplest and often the chief explanation of the diminutions in the *computed death-rates* will be found in a temporary decline in industrial urban populations. In such case estimated populations for intercensal years would be inflated over their true values, and the rates based upon them would give false evidence of improvement in the public health. Thus there may be in many cases a considerable error which would be made manifest if annual, instead of quinquennial, or decennial, censuses were taken. This would of course be true of the U.S. Census method of estimation (used by us throughout), which gives for such cities, regardless of such possibilities, the same absolute increment from year to year between any two censuses.

To any objection based on a supposed effect of the panic of 1893 on the death-rates of Lawrence and Lowell—either through actual betterment of the public health or through diminished population—we answer first of all by calling to mind Manchester, N.H., a city in all important respects similar, which we have taken as a norm. Some influence upon the death-rates of Manchester, as of other cities, during the hard times might have been expected, but the fact is that no such influence is discernible in the figures. This indicates that the rates for Lawrence and Lowell remained uninfluenced from that source.

Altho satisfied that the results of our studies on Lawrence and Lowell are exonerated by the Manchester data from any serious blame on either of these points, we have thought desirable, nevertheless, to bring forward certain explanatory and confirmatory evidence, particularly in regard to possible diminutions of population in periods of panic. And in doing so we shall include also the case of Hamburg, where a panic was caused by the Asiatic cholera epidemic of 1892.

The cholera panic at Hamburg resulted in a temporary check to the growth of the population such as might be expected from an industrial panic. In fact, not only was the growth checked, but for a time the population was actually diminished, as observed by Dr. Reincke:

> While the population of Hamburg has in recent decades increased regularly by at least 2.6 per cent per annum . . . . it has in 1892 not only failed to increase but has actually decreased by 2,808 persons. . . . . Immigration into the city, which already

at the beginning of the year was small, ceased entirely after the outbreak of the cholera, while emigration increased correspondingly ("Bericht des Medizinal-Inspektorats für das Jahr 1892," Hamburg, p. 1).

The observation thus recorded by Dr. Reincke would have been impossible without accurate statistics for the population from year to year, and we find that such statistics were in fact afforded by annual enumerations of population.

In those years in which no censuses have taken place the Statistical Bureau of the Tax Commission has made since 1868 in the city and suburbs . . . . inquiries on population and dwelling conditions, including all data necessary for official purposes ("Statistisches Handbuch für den Hamburgischen Staat," 4te Ausgabe, Hamburg, 1891, p. 24).

This inquiry, made December 1, commonly called *Umschreibung*, approximates ever more and more the exactitude of the more detailed quinquennial census. Data are taken as to name, age, occupation, etc. The results are not, however, usually worked up in much detail.[1]

We call special attention to the fact that the death-rates given in Dr. Reincke's Annual Reports as well as in the "Sanitary History of Hamburg" (from both of which works we have in this paper freely quoted and drawn data) are based upon these annual enumerations of population.

Without further comment we present the results of the annual enumerations in the following diagram, based on figures taken from the "Sanitary History of Hamburg," p. 28. The dotted lines indicate for comparison the error which would have been introduced had there been only quinquennial or decennial censuses, with interpolation of the other years by the "arithmetical" or U.S. Census method. The maximum error due to this method would in this case have been with the quinquennial only 2 per cent, with the decennial 4 per cent.

It is evident that the recovery of population set in soon again after the panic of 1892–93, and was very rapid.

Turning next to Lawrence and Lowell and the question of the effect of the industrial panic of 1893 in diminishing the population growth of those cities, we have evidence that in them, as in Hamburg after the cholera scare of 1892, recovery in general public confidence

[1] Cf. Reincke, *Gesundheitsverhältnisse Hamburgs im 19. Jahrhundert*, p. 312.

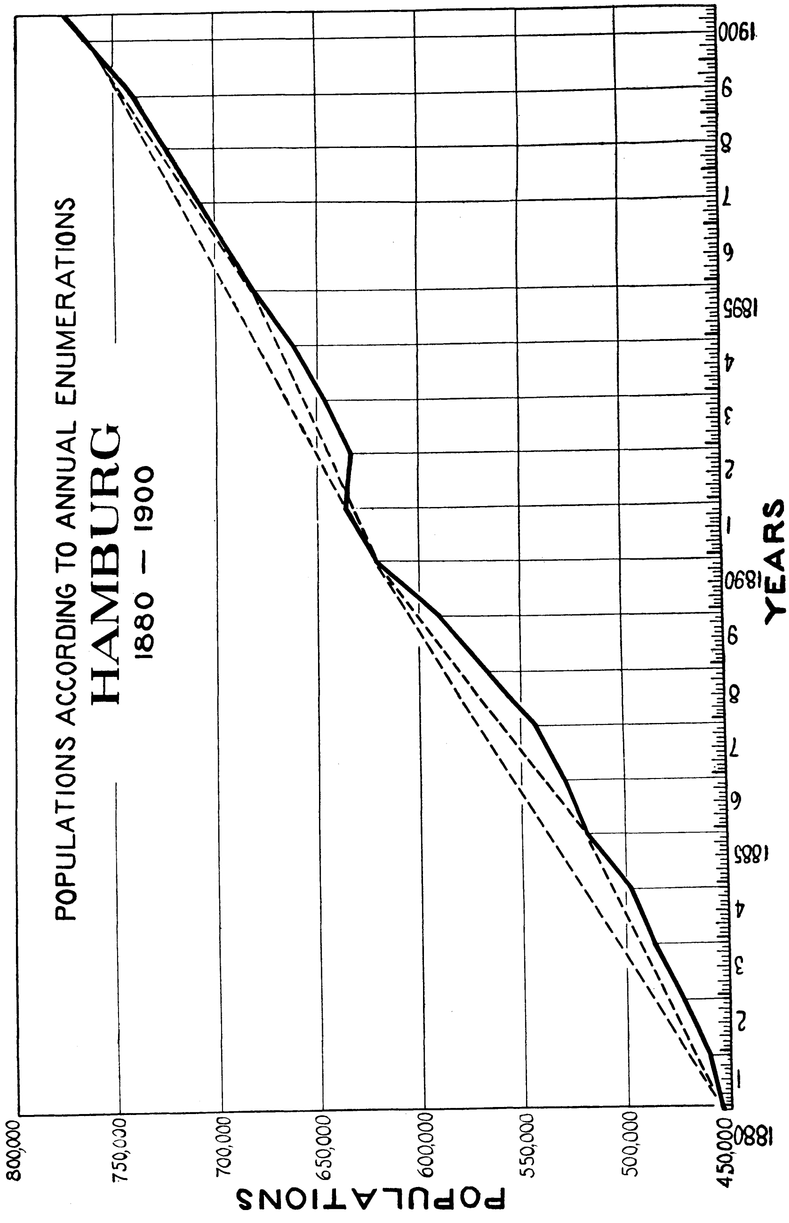
POPULATIONS ACCORDING TO ANNUAL ENUMERATIONS
HAMBURG
1880 — 1900
POPULATIONS
800,000
750,000
700,000
650,000
600,000
550,000
500,000
450,000
YEARS
1880
1
2
3
4
1885
6
7
8
9
1890
1
2
3
4
1895
6
7
8
9
1900

CHART 12.

and prosperity (with their corollary, increase of population) was early and rapid. There is first of all indication of this in the general financial and industrial movements in the United States at this time.

> Past experience has produced a number of instances where, in the second year after a great financial panic, business recovery went ahead so rapidly that it was found necessary, in the next year, to slow up. Of this the classic case in point was 1895. . . . . Sudden revival; active buying of merchandise; prediction of another "boom time"; spectacular rise in stocks, with Europe's capital enlisted; iron production surpassing all monthly records—these things were witnessed in the second year after 1893 ("The Nation," "Finance," February 24, 1910).

And this description is confirmed by the populations for Lawrence and Lowell given by the State Census of 1895. The characters of the populations had also, according to this census, remained practically the same.[1] Thus any fluctuations in quantity or character of population which may have taken place in 1893–94 were chiefly temporary. And certainly the much diminished death-rate computed for 1895 cannot be ascribed in any significant degree to error in the population statistics employed.

As an approximate indication of year to year fluctuations of population in Lawrence and Lowell, we have obtained, by courtesy of their city assessors, the total number of polls in those cities (enumerated for purposes of taxation), including practically all males over 20 years of age, as of May 1 of each year since 1889. These figures we have plotted in the following diagram, together with the total populations estimated by the so-called arithmetical method.

The panic and hard times of 1893–94 and the industrial depressions of 1903–4 and 1907–8 are seen to be clearly reflected in the curves for polls. The extent of fluctuation in these cities about 1894 was apparently somewhat greater than at Hamburg in 1892 and the following years. The indication from the Census of 1895 that the check to increase of population in 1893–94 was merely temporary, is confirmed. There was apparently also a check to growth of population in both cities following 1896, and this may perhaps be explained as a result of the secondary industrial depression which followed the revival of 1895.

The ratio of polls to total population remained fairly constant in both cities for the four census years, though more nearly so for

[1] Cf. sec. xv.

Lawrence than for Lowell. Thus for Lawrence in 1890 there were 3.88 persons in total population to each poll; in 1895, 3.69; in 1900, 3.82; and in 1905, 3.84. For Lowell the corresponding figures are

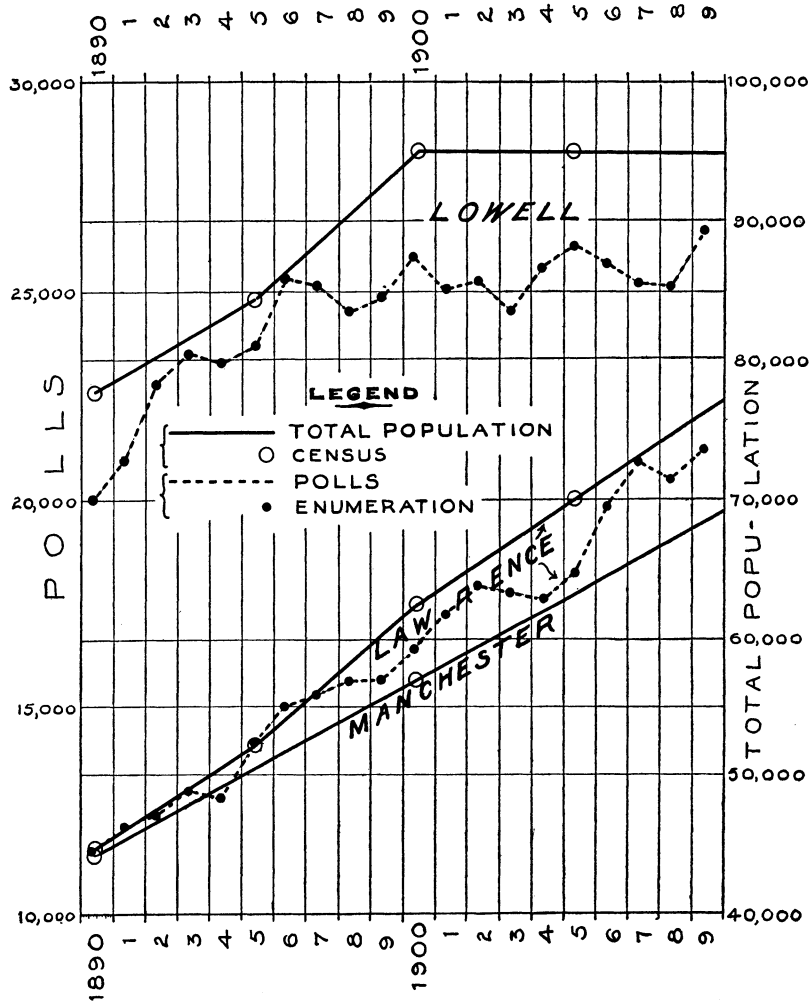

CHART 13.

3.88, 3.56, 3.68, and 3.64. These ratios afford a rough check on the accuracy of the poll enumerations, which tho of uncertain reliability, appear to be sufficiently accurate for the present purpose—i.e., an approximate indication of fluctuations of population.

In 1905 there was a diminution of the population of Lowell not paralleled at Lawrence, a difference which we have left without investigation as being unessential to our study.

We finally conclude, as to fluctuations in magnitude and character of population as sources of statistical uncertainty, that in particular years, especially where only a decennial census is to be had, errors seriously impairing the accuracy of death-rates computed from estimated populations may be introduced. The indications, however, from the curves just given, that the populations of Lawrence and Lowell had in 1895 recovered much of their former growth energy in spite of year to year fluctuations, taken with the evidence given in sec. xv on the elements of the populations and in secs. xv and xvi on Manchester as a norm, lead to the conclusion that no error seriously affecting our results can be attributed to fluctuations in magnitude and character of population.

XIX. SUMMARY AND CONCLUSIONS.

We may now bring together the various results of our study, as follows:

There is abundant evidence of the occurrence of the Mills-Reincke phenomenon, not only in the vital statistics of the cities of Lawrence and Hamburg, studied by Messrs. Mills and Reincke, respectively, but also for Lowell, Albany, and Binghamton. The phenomenon seems at first sight to be wanting in Watertown; but it is possible that in Watertown the purification of the public water-supply has been as yet relatively imperfect, and it is interesting to note that under these circumstances no diminution of the general death-rate has as yet occurred. For a fuller discussion of this point we must refer to the body of the paper.

We have not extended our studies over a larger range of cities, partly for the reason that trustworthy statistics for American cities are by no means common, and partly because of the incomplete and unsatisfactory character of investigations carried on at a distance. We earnestly hope that students of sanitary science who may fortunately have access to the necessary data for other cities will not fail to study and report upon the problems here raised. It is also greatly to be desired that similar studies should be made on the data afforded

by such cities as Washington, D.C., in which the filtration of the public water-supply has not been followed by any material decline in the death-rate from typhoid fever; for in this case such filtration would not be expected to have produced any material decline in the total death-rate. Whether or not a partial purification of a public water-supply may be expected to be followed by a moderate decline in the total death-rate we cannot say, but the experience of Watertown would seem to indicate that this is not necessarily the case.

Mr. Hazen's quantitative expression for the Mills-Reincke phenomenon, when applied to the cities which we have studied (with the exception of Watertown), appears sound and conservative. It seems likely, however, that it will be impossible in the future to confine the relation even within the broad numerical limits suggested by Mr. Hazen. In fact, Mr. Hazen himself is very careful in this particular, as will be seen by a reference to his original statement (p. 510). It is probable that the pollution of a public water-supply may consist, at one time or in one place, of much typhoidal infection mingled with comparatively little sewage, or on the other had, of much sewage only lightly charged with typhoid fever germs. In the former case the reduction in typhoid fever might be out of all proportion to the reduction in general death-rate, and in the latter case vice versa. For Hamburg we have pointed out above that the saving in typhoid mortality was slight in comparison with the saving of mortality in other diseases combined, i.e., roughly only *ca.* 1 to 16. In the other cities studied we find ratios widely different from this, e.g., at Lawrence, 1 to 4.4, at Lowell 1 to 6.0, in Albany, *ca.* 1 to 4.1 (uncorrected), and in Binghamton only *ca.* 1 to 1.5 (uncorrected). It is clear, therefore, that Hazen's theorem is merely a convenient formula rather than a precise mathematical expression.

One of the most surprising results of our study will probably be the disclosure of the remarkable relation subsisting between polluted water and infant mortality. This subject has been more fully eluci dated by Dr. Reincke than by anyone else, as will be evident from a perusal of his discussions quoted above. Our graphical demonstrations, however, are worthy of notice, as they bring out strikingly the principal facts. Students of preventive medicine will do

well to extend these studies, which promise to shed much light upon the solution of one of the most serious problems of the time.

Closely associated with infant mortality stand diarrhea and gastro-intestinal disorders (90 per cent of which in Hamburg occurred among infants under one year of age) in relation to polluted water, which now bids fair to assume a causal importance in these diseases second only to that of contaminated milk.

In regard to tuberculosis the evidence, tho less striking, is interesting and suggestive. Inasmuch as we have been unable, even after the most careful investigation, to discover any other possible explanation of the figures, we are forced to the conclusion that a considerable portion of the decline in mortality from tuberculosis in Lawrence and Lowell during the years immediately following a change from polluted water-supplies was due to that change; and in line with this conclusion a similar explanation appears more than probable for Hamburg.[1]

For pneumonia, bronchitis, and the remaining infections, our data and diagrams speak with clearness, and we need not repeat the discussions we have already given in the preceding sections.

We have examined in detail the influence of fluctuations of population upon our statistical results, and find that no serious error has been encountered by us in that direction. It is certainly an interesting fact that the great panics have rarely if ever coincided with either federal or state censuses; but we find no reason to believe that the declines in either typhoid fever or the general death-rate in Hamburg, Lawrence, or Lowell, altho these happened to coincide with periods of panic, were in fact attributable to decrease of population.

Finally, the question naturally arises, to what is the decline of mortality observed in the Mills-Reincke phenomenon for diseases other than typhoid fever due? A little reflection will show that increase of vital resistance, due perhaps to the use of a purer drinking water, might produce this effect, while, on the other hand, the same results might be reached by an exclusion of disease germs formerly present and working upon the bodies of their victims. Or, as a

[1] See p. 185 of our paper in the volume *Tuberculosis in Massachusetts*, mentioned on p. 491 above.

third possibility, the phenomenon might be due to a combination and co-operation of these two factors.

It is interesting to observe that Mr. Mills in his writings upon this subject, without especially committing himself to either hypothesis, has apparently had in mind chiefly an increase of vital resistance, while Dr. Reincke has expressed himself rather as looking to the removal of disease germs previously present.

The facts at present in our possession do not allow us to settle the question beyond peradventure, and this problem, like many others raised throughout our paper, requires further elucidation.